**FROM BROWNFIELD TO GREENFIELD:**

**A SOCIAL AND ENVIRONMENTAL REMEDIATION PROJECT**

A CREATIVE PROJECT

SUBMITTED FOR THE GRADUATE SCHOOL

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BY

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# TABLE OF CONTENTS

# TABLE OF FIGURES

# CHAPTER 1 – INTRODUCTION

Muncie, Indiana is like many other US cities in that is has properties within the city bounds that have been abandoned or closed due to lack of business, or have contaminants above maximum legal levels for human use or occupancy. When a property degrades to the point that it is unsafe for residential or even industrial use or development, they are categorized as a "brownfield" and listed in the state and national brownfields registry. Generally, these properties are considered too expensive and too much of an inconvenience to clean up, so city developers and industries look for more attractive and untouched land on the outskirts to build upon, contributing to the ongoing American epidemic of urban sprawl and loss of "greenfields." This, of course, does not solve the existing problem and leaves hazardous sites all over the city which degrade environmental conditions, human health, and property values in the immediate area.

Community members who live and work in and around brownfield sites are those who suffer the most. Most brownfields are located in economically disadvantaged areas, and negatively impact those who live or work there. Studies have shown a direct connection between the proximity of contaminated soil and water to chronic health problems such as cancers, some neurological disorders, birth defects, respiratory problems, and a variety of metal poisonings. Those who live in these areas are generally economically disadvantaged, which also has a direct connection to their overall stamina for physical and social health. They are financially or socially unable to move away and so must suffer the consequences of being exposed to contaminated sites.

Another reason brownfields tend to be found in economically disadvantaged areas is because there is not an incentive or financial backing to remediate these sites. Ideally, they would be remediated or re-developed by current or former owners, or the city could make efforts to clean it up. This costs money so many companies avoid it unless pressured by regulations or protests by the community. Many cities have to focus on cutting spending so they often don't have the leisure to deal with low-profile projects especially when lobbied by these companies. The working class poor often don't have the time, energy, or money to protest these situations even when they are made aware of them.

With the rising demand for "sustainable" and "green" solutions in new architecture, urban planning and development, and landscape design, attempts at reclaiming the abandoned inner city and urban sites have been made. Land costs have also factored in, showing how re-developing abandoned areas saves more in the long-run when considering materials, travel time and costs, rising fuel prices, and the value of greenfield properties in relation to the demand for agriculture, the need for green spaces, and quantifiable environmental benefits.

With all of these issues considered there is a need to clean up urban brownfields in a way that will not exacerbate the problem or just offer a temporary solution, and a need to do so in an environmentally and economically feasible way.

## Project Significance

This project aims to develop a process and design program for a forest and remediation demonstration park on the Peloquin property in Muncie, Indiana. This program and process template will be flexible enough to be altered and used on other brownfield sites within the city. It presents strategies that will help clean the soil and groundwater using a combination of remediation processes that are non-invasive, and in the long-run will improve the social and environmental conditions for residents in the immediate area. The final phase of the project will incorporate remediation and native ecology demonstration areas. To extend the community's involvement beyond passive observation once remediation is complete, a community-run garden will be incorporated into the site.

The project provides opportunities for members of the community to become stewards of this site. They can learn how to create a productive area out of a once-abandoned and contaminated site; it can help provide maintenance and educational jobs for the community that will last over a long period (at least for the projected time for full remediation), and the opportunity to supplement nutritional needs for people who do not necessarily have money but can provide time to cultivate food for themselves.

Similar applications of basic components of this design can also be applied to a variety of sites in the Muncie region needing remediation, and brownfield sites in other cities, potentially creating a series of spatially- or thematically-connected park spaces out of once unusable land. This design template could be used for other parks in areas of concern as part of the revitalization of the city of Muncie.

## Scope

The primary goal of this project is to present a design proposal that will lead to the remediation and development of a designated urban brownfield in Muncie, Indiana, through several phases of bioremediation and usability, to the point where it can safely be used as an urban agricultural site. This project looks at developing a master plan and remediation process timeline for the site within the Peloquin property. The project design parameters incorporate the history of the site, considers the uses of adjacent land and sites of relevance within the immediate area, and focuses on creating a long-term comprehensive plan to encourage the use and sense of ownership and stewardship by the local community in an effort to help support them physically and socially.

Among other things this project considers the cultural and environmental history of the site, current contamination findings and existing bio/geological conditions on the site, existing local recreation and park services, landscape design and place-making principles, long-term management and development, and bio-remediation processes.

## Methodology

The methods used for this project follows a traditional landscape architecture research project design process. An observed problem area in the city prompted research in brownfield remediation, with a focus on using phytoremediation techniques. A site (the Peloquin property) that could be used to explore this interest was identified. A series of goals and objectives were then compiled and more extensive research was conducted to begin addressing the goals. From there, a program and series of design concepts were developed to further address the goals, while precedent studies focused on successful existing projects and processes that address similar situations. Design and documentation followed.

The problem was identified within the frame of interest, primarily healing degraded landscapes, and preliminary research was conducted on that subject. A potential project and basic set of goals and criteria was created that would encompass environmental and social concerns. The Indiana Brownfields list was researched for potential sites within an area that would be feasible for study and site visits, and would fulfill the project site criteria. By using GIS mapping, the potential site data was mapped and assessed by looking for sites that fulfilled the most criteria: a registered brownfield located in Muncie, Indiana, adjacent to more disadvantaged areas and areas of high density, near existing park systems and residential areas, accessible by public transportation, and near a body of water. A multitude of sites were found through this process and many were eliminated according to the conditions of the criteria, narrowing down the choices to the one that fit best (Appendix A, Fig 1.1, pg. 128).

The most suitable site for the project was the Peloquin property. Data regarding the existing contaminants was included in this report and for this project was translated into graphic diagrams expressing locations and contaminant concentrations on the site. Other important information regarding the site was researched, including local conditions and site history. Site visits were conducted to determine the overall “feel” and visual condition of the site.

A quantitative method was used to collect data on plants suitable for biological remediation, other applicable remediation methods, and their specific uses and success levels when applied to different contaminants. This list changes depending on the contaminants and environmental and geological conditions of the site. Other quantitative data include the types of plants suitable for an urban garden and in raised beds or pots depending on the level of contamination of the site and their suitability.  Projects that successfully dealt with brownfield remediation and the improvement of living conditions through community efforts were researched, and the applicable processes and methods were considered and modeled for this project.

From these assessments, diagrams and a proposed master plan were created.  A process template and timeline were designed from this that could be applied to different types of sites and contaminants; it depicted the process and showed at different stages what can be grown or used on the site, including safe areas for participation by community groups. The research was analyzed according to relevance and by reliability of the source, then the data was synthesized to support or augment the specific needs of the site and program.

A phased design, timeline, and implementation plan for the project site was formulated, illustrating different stages of rehabilitation over time and accessibility by the public, to the point where the site is assumed safe enough to install a harvestable community garden. The phased design proposes to incorporate as much community input and hands-on work as safely as possible, encouraging social and physical healing in the community as local citizens work together to heal the landscape.

## Definition of the Problem

*Preconceptions:*

Currently there are preconceptions and misconceptions associated with brownfields and developing urban agriculture sites on them (Appendix A, Fig 1.2, pg. 129).  Brownfields are seen as permanently contaminated and not suitable for food production due to human health risks

(Heinegg, 2002). However, if properly tested, assessed, and treated, sites can be rehabilitated to acceptable standards. (Appendix A, Fig 1.3, pg. 129) The United States Environmental Protection Agency (US EPA) indicated that phytoremediation techniques applied to many different brownfield sites have successfully removed contaminants (Appendix A, Table 1.1, pg. 130) such as petroleum hydrocarbons, benzene, toluene, ethylbenzene, and xylene (BTEX), polycyclic aromatic hydrocarbons (PAH), polychlorinated biphenyls (PCBs), trichloroethene (TCE) and other chlorinated solvents, ammunition wastes and explosives, heavy metals, pesticide waste, radionuclides, and nutrient wastes (Environmental Protection Agency, 2001A). What must be considered is how to balance the environmental and safety risks of employing community member participation on site and in the remediation process, while addressing valid issues concerning quality of life, open space access, social inputs, and public perception in a long-term and sustainable fashion (Gute,2006).

*Physical and Social Health:*

"Thirty-one million Americans live in homes with limited or uncertain access to adequate nutrition. The same demographic that disproportionately suffers from food insecurity, i.e., low income minorities, is also prone to higher rates of diabetes, stroke, asthma, obesity, heart disease, cancer and other chronic health issues" (Hallberg, 2009). At the same time we are producing huge amounts of subsidized food that is inefficiently distributed, further complicating these health issues. Community-run gardens and projects have been successfully used to help augment food availability to these families and to bring communities closer together.

Using community-produced food can help address economic, environmental, and social challenges to the community, provide easy access to healthy food, confront transportation issues, decrease the distance the average meal travels, and provide activities and projects local citizens can participate in together as a community (American Planning Association, 2012). Community stewardship has also shown to be a successful way to engage local people in the long-term care of a site, especially in an area that needs public space. This project explores the social and economic effects of bioremediation and urban agriculture as a possible means of community remediation in disadvantaged areas.

In New York City alone, 7.1% (about 11,000 acres) is currently vacant and could be rehabilitated into productive landscapes (EPA, 2010). Similarly, the 2000 US Conference of Mayors estimated from a survey of 231 cities, that brownfield redevelopment could produce over 550,000 new jobs and up to 2.4 billion dollars in tax revenues every year (McCarthy, 2002). Many of these jobs could benefit local residents and people with lower skill levels needing jobs. The benefits of reusing urban brownfields include the revitalization of the site's history, health, and minimizing the use of greenfields or existing natural habitat for development; healing the site's image; and decreasing the public's health and safety risks (Simmons, 2002). Community involvement can foster a sense of identity and propriety with the site as it is healed and by providing jobs, eventually improving property values. Such work also provides a supplemental food source can also improve the communities' economic standing.

*Biological Remediation Applications:*

Biological remediation techniques such as bioremediation and phytoremediation are proven, viable, and less invasive options to treat damaged sites than a clay cap or total soil removal, (which are often expensive processes), and are successful at remediating most types of contamination (Appendix A, Table 1.2, pg. 130 and 1.3, pg. 131). Sometimes, however, it is difficult for communities to trust the claims of companies or authorities, and the technologies are not always fully understood. Full soil removal is often perceived as a better process than any of the bioremediation techniques available (Kocher, 2002). One can imagine the contaminated soil being taken away and "clean" soil replacing it, yet it is difficult to see plants remove toxins while trusting that soil tests are accurate. Involving the community in much of the process can help alleviate these concerns and misconceptions. "In the face of changing circumstances, community-based institutions can provide continuity, serve as a forum for creative negotiations, and act as a lever to keep brownfields projects viable" (Siegel, 2005). In addition, when using phytoremediation methods, there is a concern as to whether the benefits outweigh the disadvantages. Additional concerns include what happens to the contaminated materials once harvested (Appendix A, Table 1-4, pg. 131).

## Limitations and Assumptions

Due to limitations such as time constraints and limited access to the site, the project is based upon a series of assumptions.

1. Soil contaminant types and concentrations for the project site are based on the findings of a brownfield assessment completed in 2008, and their extent is based on their chemical characteristics, the soil type and depth, and projected surface water flow.

Five soil borings were conducted: one at each corner of the site, one by the fill piles, and a surface test of the fill piles. All levels of contamination across the site are extrapolated from the soil borings and fill pile tests conducted in the brownfield assessment conducted by Symbiont in 2008. A more accurate approach would be to conduct surface soil surveys and contaminant tests, using the findings along with the soil borings published in the brownfields assessment. However, since the site is so large, such testing at that time was not feasible, therefore the site inventory and analysis were extrapolated from the original assessment.

2. It is assumed that full site remediation will take place in three main phases within a 10-year timeframe; in other words, the soil and groundwater across the entire project site will be sufficiently free of the contaminants for urban agricultural purposes.

Using the proposed remediation processes the expected outcome of each design phase is full removal of the specified contaminants within the time allotted. When this project is actually built, the rate of remediation will vary depending on many factors that can change over time from one part of the site to the other. In addition, soil and groundwater tests would be periodically conducted to determine contamination levels across the entire site, and the planting choices and advancement of the phases would be based on the findings.

3. Methylene chloride is a difficult contaminant to remove and is present in the northern part of the site. It is assumed that this project will have successfully removed it by Phase Two.

According to the Phase I Environmental Site Assessment (Symbiont, 2008), the upper portion of the site is contaminated with methylene chloride, a difficult contaminant to remove with biological remediation, so mechanical or chemical methods are usually employed. The project design is based on the concept that by the second phase (three years in) this contaminant will have been successfully removed and the area prepared for further remediation.

4. The White River is not a potential off-site source of contamination from other sites upstream in this project.

For this project, the possibility of river water entering the site is not taken into consideration; the river is considered to be of no concern other than possible entry of contaminants to the river from the site.

# CHAPTER 2 – EXPLORATION OF TOPICS

## Brownfields in Urban Environments

Brownfields are becoming more of a focus of the public and local government as we come to the realization that abandoning properties and spreading out to build upon undeveloped land is not feasible in the long-run. Federal and state programs are being developed to specifically handle brownfield situations, and to develop regulations and provide funding for their remediation (Appendix A, Table 2-1, pg. 132). "From 2003 to 2005 more than $225 million in federal grants were dispersed to states to promote the redevelopment of contaminated landscapes" (Berger, 2006). In many cases, the redevelopment of these sites, especially in inner cities, has been focused on the purpose of making the site usable for residential or commercial purposes. This is a good approach as "through brownfields redevelopment, cities can reap significant environmental and economic benefits through site improvements, job creation and new commercial, industrial and residential opportunities" (United States Conference of Mayors, 2006) and the companies who buy and reclaim the land can gain a significant profit margin on resale, depending on what cleanup process they use (Appendix A, Table 2-2, pg. 133). This type of land takes up significant amounts of inner city space and, once reclaimed, can provide re-development areas preventing urban sprawl and development of greenfields (prime undeveloped land). Many cities have expressed preferences for policies that encourage re-use; “they expect 60 per cent of all new housing will be built on brownfield and inner-city sites. With the scarcity of urban land for new building there will be intense pressure on local government to develop on underutilized allotment sites” (Ferris, 2001).

According to the Environmental Protection Agency (EPA), since the creation of the brownfield program, it has leveraged 72,434 total jobs nationwide. In a survey looking at the 2011 fiscal year, urban brownfield remediation projects have leveraged on average $18.29 for every EPA dollar expended, shown a 32-57% reduction in vehicle miles traveled (when developing brownfields instead of greenfields on city margins), and can increase residential property values 2-3% when nearby brownfields are addressed. It promotes area-wide planning, decreases stormwater runoff, and surveys also indicate a reduction in crime rates in the recently revitalized brownfield areas (EPA, 2012).

Most inner city remediation and redevelopment projects focus on using the land to build upon, rather than cleaning it for open or green space. This is most likely because of the enhanced value of the property once it is considered safe to use. However, there is a growing demand for green space in cities where people who may not have the time or luxury to go out to an established park or garden area. There is “a growing recognition among community groups and environmental organizations that brownfields hold enormous potential for “greening” city environments, through the implementation of parks, playgrounds, trails, greenways, and other open spaces” (De Sousa, 2003). Since the city infrastructure is already well established, interventions at a smaller scale in abandoned or underutilized properties can provide better access to more green space without causing problems for people living or working in the area. By utilizing less invasive remediation processes, we can also reduce the disruption caused to the community.

Other aspects that work in the favor of remediation are “the social costs and benefits of greenfield development versus brownfield redevelopment; and meaningful community participation” (McCarthy, 2002). When a brownfield exists in a community setting, local citizens realize that it negatively impacts them socially, economically, and physically, and once they identify the problem they will put effort into correcting it. This is a great way to make sure long-term remediation projects will be emphasized and maintained. “In the face of changing circumstances, community-based institutions can provide continuity, serve as a forum for creative negotiations, and act as a lever to keep brownfields projects viable” (Siegel, 2005). Efforts are being made worldwide to change how we develop and expand cities. Many redevelopment projects incorporate a sustainable community plan that focuses on providing jobs, social venues and opportunities, and local production of renewable energy and food sources. There are efforts not just to provide areas people can use, but to develop connections and imperatives within the community that will last longer than a built place. “The focus on brownfield remediation has almost exclusively stressed the context of city planning and real estate redevelopment, and the policy development has proceeded accordingly” (Heinegg, Brownfield Remediation, 2002).

Allowing the community to participate in a remediation project strengthens their connection to it and creates a more successful program and site. (Appendix A, Table 2-3, pg. 134) Designer-led project charrettes are often employed to better understand the needs of the community and future intentions for the site. “This charrette allowed the community to envision a future reuse of the involved properties... forming a viable partnership with the community leadership. A key element was also engaging the end users of the site as directly as possible in the planning of the design" (Gute, 2006). The remediation projects were, however, led by a design team or company to ensure the site was fully remediated. There are many such companies who specialize in biological brownfield remediation processes (Appendix A, Table 2.4, pg. 135 and 2.5, pg. 136) and landscape architecture companies who will collaborate with them on projects.

An added benefit to developing brownfields is that it encourages people to think of the process of development, use, and redevelopment or remediation as a cyclic process and part of a larger system rather than a linear process of development, use, and abandonment. "The reclaimed landscape is originally treated more as a system than a form and more as an infrastructure than an object. Eventually, through processes independent of its original state, the reclaimed landscape evolves into a new totality that locally adapts under the duration of time" (Berger, 2006). This type of thinking has led to community-oriented sustainable grassroots projects or full re-development plans. It is important to encourage their involvement as "proactive communities allow a greater amount of sustainable development to be achieved… at the 'grassroots' level, i.e. in the community; a bottom-up approach often at odds with the traditional economic development model" (Holland, 2004) especially when remediating a site located within the community.

Reusing a site also allows us to experiment with design and technological possibilities that would normally not be feasible on a property that is of a higher value. These experiments and processes can be applied to other sites and situations when they prove successful. A bioremediation process and system designed for a specific site takes into account all of the contextual and environmental conditions affecting it. In turn, parts of it can be applied to other local sites or projects with similar issues. "Reclamation sites are viable testing grounds for new ecologies that allow for other constructs of "nature" to flourish…. Some of these new constructs will become applicable globally to other altered landscapes and urban areas" (Berger, 2006).

### In Relation to Human Health

Brownfields have a direct impact on human health. The contaminants, such as metals, that leach out of landfills, wash out of mines, collect in the air and water, and filter into the groundwater all negatively affect humans at certain levels. Most do occur naturally as pure elements in the environment; however, they are usually found in trace quantities or bonded into compounds that are not as hazardous. Humans and other organisms need metals such as zinc and copper to function properly; however, the amounts that are re-entering environmental cycles are above natural levels, and humans are being exposed to concentrations that may pose negative impacts. Increased levels of nitrates, mercury, arsenic, and even radionuclides in the environment has caused many forms of chronic and debilitating conditions from birth defects to brain damage and many forms of cancer. Generally, the people most exposed to these conditions are the local citizens who don't necessarily know about the problem, such as where a mine or industry dumps wastes and covers it up, or they are unable to move away due to financial or social reasons. The issue worsens over time, not only degrading human health but also impacting citizens' emotional and mental well-being and lowering land values. "Contaminated communities experience the loss of economic value, deterioration of social and ecological relationships, and diminution of health and well-being of residents" (Kocher, 2002).

These communities also often suffer from a lower economic standing which is shown to have a direct impact on their diet and food choices. Disadvantaged families, especially inner-city ones, don't often have the money to buy, time to prepare, or access to fresh foods which have to be shipped in from elsewhere. It seems easier and cheaper to buy a "meal" at a fast food restaurant, when they are in a rush to get themselves to school or work. "The issue of poor diet has now been elevated from a personal health issue to a public health crisis. For the first time ever, health officials predict today's children will live shorter lives than their parents due to obesity and chronic disease-related mortality" (Cohen, 2004). People understand that there is a health crisis and eating this type of food is inadvisable, but in most cases there really is a lack of options. "Lack of access to nutritional foods in low-income communities has led to poor diets which are high in caloric intake but inadequate in nutrients. One important step towards stemming chronic diseases linked to poor or inadequate diets is ensuring access to healthy nutritious foods in the most vulnerable communities" (Hallberg, 2009).

The opportunity to plant a "victory garden" to supplement expensive food bills is just not as available to people in the city or on rented properties as it is in rural areas. Urban dwellers also miss out on their connections to nature and the benefits most take advantage of when gardens or parks are readily available. In surveys determining why there is such a demand for urban parks and agriculture, "the most common reasons reported by the coordinators for participation in community gardens were access to fresh/better tasting food, to enjoy nature, and because of health benefits, including mental health" (Armstrong, 2000). If opportunities such as community gardens and integrated edible agriculture landscaping and green space are available, community health will improve holistically. This also helps to improve local residents' mindset regarding how to deal with "nature," outdoor physical activity, and our role as stewards to the land and to each other. People will tend to think more about how things work, how they treat their body, and what they are eating. "People involved in sustainable agriculture are more likely to have a systems orientation. They are concerned about where food comes from, how it is produced and transported to the consumer" (Cohen, 2004).

### Benefits and Methods of Urban Agriculture

Several benefits seen in developing community gardens on remediated sites include "improved access to food, improved nutrition, increased physical activity and improved mental health. Community gardens were also seen to promote social health and community cohesion" (Wakefield, 2007). Providing the opportunity and means to start a garden enables families and community members to meet and work together to produce something that they can take pride in. Strengths, Weaknesses, Opportunities, and Threats (collectively known as SWOT) analyses on various projects have shown that "community gardens are seen to benefit the community as a whole, by improving relationships among people, increasing community pride and in some cases by serving as an impetus for broader community improvement and mobilization" (Wakefield, 2007). Urban agriculture can be used not only to provide a source for food supplementation, but also a deeper understanding of and a sense of ownership of a particular area of land that exists within the community's purview.

Such projects and changes to basic food system perceptions encourages people to find ways to be more sustainable, especially with diminishing resources and growing interest in alternative energy sources, to shop locally for food or products and learn about local systems that they are a part of and can control. Just having locally-produced food helps in the conservation effort since "other natural resources, such as energy for transportation and cooling, can be conserved through urban agriculture" (Smit, 1992). Any fuel or money that can be saved through this endeavor can help families better handle personal incomes, especially in times of personal financial crises.  Most communities start this kind of activity specifically as a means to provide a safety net in the same way food pantries do; however, they provide food types normally not provided by such organizations and help nutritionally supplement what is normally offered.  "Access to good quality and affordable food often is a concern among community gardeners and community, especially in low income neighborhoods where access to affordable, high quality produce is limited" (Saldivar-Tanaka, 2004).

Utilizing brownfield sites as a source for community gardens is an entirely feasible endeavor.  There have been many cases of not only the community developing a garden on a once-contaminated site, but also participating in the cleanup process with the goal of such a public use.  "Across the country, brownfields are being transformed into housing, commercial buildings, mixed use developments, and parks. Though there are myriad reuse options for brownfield sites, agriculture-related uses present exciting alternatives to traditional redevelopment" (APA, 2012).

Most urban brownfields are not large industrial facilities or properties-- they are usually smaller sites contaminated by dry cleaners and auto repair shops, so remediation and re-use by locals, rather than large-scale development would suit best.  It seems that "gardening on brownfields appears to be a new concept… with interest from many gardeners and researchers across the country about techniques, locations of existing gardens and availability of space. Concerns were raised by some about the safety of gardening on brownfields" (Devine, 2007).  If the soil is fully remediated then there should not be any problems with safety.  If the people involved with the garden also take part in the remediation process then there should be less doubt and confusion.  There have also been garden projects that have been built on partially remediated sites.   These generally utilize raised beds with root barriers preventing the plants from gaining access to the contaminants, and agriculture choices based on what types and levels of contaminants there are and how the plant is used. Cutting flowers are plant choices often used in situations where people are uncertain about the quality of the soil, or plants that would only have the unused parts take up the contaminants. In the event or possible concern about vegetable contamination, certain plant types are more or less suitable for urban planting (Fig. 2.1).

***Most Suitable***

- **Vegetable Fruits and Seeds: tomatoes, eggplant, peppers, okra (seed pods only), squash (summer and winter), corn, cucumber, melons, peas and beans (shelled), onions (bulb only)**
- **Tree Fruits: apples, pears**

***Least Suitable***

- **Green Leafy Vegetables: lettuce, spinach, Swiss chard, beet leaves, cabbage, kale, collards**
- **Other Vegetables: broccoli, cauliflower, green beans, snow peas**
- **Root Crops: carrots, potatoes, turnips**

**Fig. 2.1.** Plant varieties suitable for contaminated sites (Turner, 2009, pg. 17)

## Brownfield Contaminants

Contaminants can include anything that is harmful to the environment or people at any concentration. The following section focuses primarily on the contaminant types found in the project site and the methods that could be used to remove them. For common sources, types, and remediation methods see Appendix A, Table 2-6, pg. 137.

*Heavy Metals:*

Heavy metals are a common contaminant found in urban brownfields. These naturally exist as trace elements in the soil at different concentrations. The impact they have on plants and animals in any given system and the possible ways or forms of absorption and bioaccumulation determine their accepted or legal levels. The heavy metals explored in this section include chromium, lead, nickel, and zinc. Other element types and their removal methods focused emphasized in this project are referenced in Appendix A, Tables 2-7, pg. 137 through 9, pg. 138. These are of concern, as they are found to be above the Indiana RISC Default Closure Levels (RISC DCL's) indicated in the Brownfield Assessment Report for residential use, or above. Zinc is the only metal of concern found in the project site above legal levels in the groundwater sampling.

Chromium (Cr) is a metal that is essential in human and animal diets and is "an essential nutrient for humans and shortages may cause heart conditions, disruptions of metabolisms and diabetes." However, excessive quantities or undesirable forms, "in animals chromium can cause respiratory problems, a lower ability to fight disease, birth defects, infertility and tumor formation… People can be exposed to chromium through breathing, eating or drinking and through skin contact with chromium or chromium compounds" (Lenntech, 2011).

Sources for chromium includes "the chemical manufacturing industry and combustion of fossil fuels… electroplating, leather tanning, textile industries" and other such manufacturing industries (Pichtel, 2007). The natural average concentration found in any given soil is 100 mg/kg with a range of 1-1,000 mg/kg. The legal RISC DCL residential level is 38 ug/kg and 120 ug/kg for industrial use (Appendix A, Fig 2-1, pg. 139). Chromium attaches strongly to soil particles, settling out of the air and bonding to sediments in water, and can be a difficult element to extract. The presence of chromium in the project site is most likely linked to the past existence of the automobile maintenance shop and the foundry sand and slag dumped in the north of the site. Chromium is often used for "alloys such as stainless steel, in chrome plating (for rust-proof auto parts) and in metal ceramics. Chromium plating was once widely used to give steel a polished silvery mirror coating” (Lenntech, 2011). Two forms commonly found in brownfields are chromium III and chromium VI. The potential presence of chromium VI is problematic as it travels more freely through soil and it is more hazardous to human health.

Lead (Pb) is another metal found in the environment as an ore but is more commonly deposited by industrial practices. There are no beneficial effects of lead in humans or any other organism. “Lead is one out of four metals that have the most damaging effects on human health. It can enter the human body through uptake of food (65%), water (20%) and air (15%)” (Lenntech, 2011). Lead causes a wide range of neurological and physiological damage when absorbed in any form. Brain damage in children has been a concern and focus when eliminating lead from products such as paint and gasoline. However, it still exists in certain industries and byproducts, and has a tendency to remain in the atmosphere when combusted, which extends its life cycle. This element bioaccumulates at every level of the food chain and in all life-forms.

The natural average Pb concentration in soil is 10 mg/kg with a range of 2-200 mg/kg. The residential RISC DCL is 81 ug/kg and 230 ug/kg for industrial use. Most occurring in the environment is due to human activities, especially from the burning of lead salts in gasoline which become airborne and settle out in the area of combustion, or will travel in the atmosphere and are deposited in rain. Lead is currently limited in many consumer products, yet its use in the past still show heavy contamination. Lead now enters the biosphere primarily through “metal smelting and processing, secondary metals production, Pb battery manufacturing, pigment and chemical manufacturing, and disposal of Pb-containing waste” (Pichtel, 2007). Once in the soil it has a tendency to remain there and not travel through groundwater unless transported with sediment. Its presence in the site is linked to the railroad tracks and the roads bordering the site.

Nickel (Ni) is used in steel, other metal manufacturing, and many types of industrial products. It is essential in small quantities in humans and other organisms, but its specific functions are still not clearly understood. Nickel influences development, skin and bone health, and some enzyme and hormone production. A deficiency leads to hormonal imbalance, abnormal development, and changes in skin and hair, while too high of a concentration can be toxic or carcinogenic, especially if inhaled. Other possible health concerns include skin sensitivity, respiratory problems, birth defects, and heart disorders. Nickel "will adsorb to sediment or soil particles and become immobile as a result. In acidic soils and groundwater however, nickel is bound to become more mobile and it will often rinse out to the groundwater" (Lenntech, 2011). High nickel concentrations can damage plants in sandy soils or algae in surface water, yet microorganisms have been shown to adapt after an initial die-off.

The natural average Ni concentration in soil is 40 mg/kg with a range of 0.2- 450 mg/kg. Higher concentrations occur naturally in clayey and loamy soil. The residential RISC DCL is 950 ug/kg and 2,700 ug/kg for industrial use. For groundwater contamination the closure levels indicated in the Phase I Environmental Site Assessment (Symbiont, 2008) are 0.0083 uk/kg for residential and 2.0 uk/kg for industrial use. "Nickel is released in the emissions from mining and metal-processing operations from municipal waste incineration, and from the combustion of coal and oil" (Pichtel, 2007). Other sources include artificial fertilizers in agricultural practices, stormwater runoff, leachate, and sewage treatment.

Zinc (Zn) is another essential trace element in the human diet. Too little causes a loss of appetite, slowed healing, and sometimes birth defects, but "too much zinc can still cause eminent health problems, such as stomach cramps, skin irritations, vomiting, nausea and anemia" and respiratory problems if inhaled (Lenntech, 2012). Zinc can also negatively impact plant growth and the processes of microorganisms and worms when decomposing organic matter. Zinc bonds with sediment but can dissolve and travel into the groundwater so contaminated bodies of water will deposit zinc into soils down-gradient (surface and subsurface).

The natural average zinc concentration in soil is 50 mg/kg with a range of 17-125 mg/kg. The RISC DCL is 10,000 ug/kg for both residential and industrial use. "The main use of Zn is as a corrosion-resistant coating on iron or steel… and metal processing… released to the atmosphere as dust and fumes from zinc production facilities, automobile emissions, and fuel combustion" (Pichtel, 2007). The presence of zinc in the soil of the project site is likely a result of the foundry, automobile repair shop, and the roads around the site.

*Aromatic Hydrocarbons:*

Naphthalene (NPTH) is a white, solid, aromatic hydrocarbon that is found in petroleum oils, lubricating oils, pesticides and moth balls, and is used to make PVC. It is a contaminant that evaporates easily and is very volatile when mixed with air. It is often found in oil spills, areas involving automobile maintenance, and when wood or fuel is burned. Naphthalene can be absorbed through skin, in drinking water, or inhaled and can cause damage to red blood cells and anemia. "Exposure to a large amount of naphthalene, such as by eating mothballs, may cause nausea, vomiting, diarrhea, blood in the urine, and a yellow color to the ski." (Agency for Toxic Substances and Disease Registry, 2005).

The RISC levels indicated in the Phase I Environmental Site Assessment (Symbiont, 2008) are 700 ug/kg for residential closures and 170,000 ug/kg for industrial. Sources for this contaminant likely include the auto repair shop, roads and parking, and potential spills from the railroad tracks. Naphthalene binds weakly to soils and sediments and can become dissolved in water; however, it usually evaporates or is broken down very slowly by existing microorganisms in the soil and water.

2-Methylnapthalene was the only BNA (base neutral acid) detected in the project site. It is a solid and was found in the same location as naphthalene. The characteristics and effects are relatively the same as with naphthalene. There are no RISC DCLs given for 2-methylnapthalene in the Phase I Environmental Site Assessment (Symbiont, 2008).

*Volatile Organic Compounds:*

Methylene chloride, or dichloromethane (DCM), is a chlorinated solvent found in paint thinners, used for chemical processes and extractions, and is also used for decaffeinating coffee. It is a type of VOC (volatile organic compound) which easily vaporizes, becoming an airborne health hazard. Primary exposure of this contaminant for humans is in the air, and it is highly mobile in the soil and water. "Average daily intake of dichloromethane from urban air has been estimated to range from about 33 to 309 µg. Exposure to dichloromethane in indoor air may be much higher, especially from spray painting or other aerosol uses and from paint removal and metal degreasing" (International Agency for Research on Cancer, 2012). Once it is released into the air it takes about 53 to 127 days to break down by half. This contaminant also shows up in processed and highly processed foods, and there are legal limits for the amount used in processing, depending on the type of food and length of exposure. Methylene chloride was banned in many products such as hair spray, and there are attempts to phase it out completely because it causes severe respiratory problems, chemical burns on skin, and many types of cancers.

Methylene chloride does not occur naturally in the environment. It was developed in 1840, became an important chemical during WWII, and is now only found as a byproduct of industrial and human processes. The RISC DCL indicated in the Brownfield Assessment Report is (23 ug/kg) and (1,800 ug/kg) for industrial use. Most of the tests for this compound have been disclaimed as a test error as it was also found in the test blanks; however, one test site is believed to be accurate and the potential source is waste from the auto repair shop such as degreasers or paint thinners.

### Remediation Processes

This project focuses on using primarily biological processes to contain and remediate the contaminants found in soil and groundwater at the Peloquin site. These processes do, in general, take a longer period of time to fully remediate soil; however, they are not as invasive as many current methods. Full soil removal and cleansing is costly and severely disturbs the site, and, generally, the toxic contaminants are placed in another landfill that causes problems for someone else. Capping the site with a layer of clay, concrete, or asphalt does not clean up the contaminant which may leach out in the groundwater if the cap is breached. Some projects incorporate soil microbes under a cap, but this system only works if the microbes do not need access to oxygen, and even then the existing soil community is damaged by sealing. Chemical treatments can damage the soil and may not be very effective in dry soils or for contaminants that have spread deep underground (Appendix A, Tables 2-10 and 11, pg. 140).

Other than using a mechanical process to extract the methylene chloride from the northern part of the site, this project will use bioremediation, mycoremediation, and phytoremediation techniques to remove the contaminants.

*Soil Vapor Extraction:*

Soil vapor extraction will be used to remove methylene chloride from the soil. This works by drawing air through a network of wells in the ground. Heated air is forced into the ground to increase the rate of volatilization and create an updraft of contaminated vapor to rise and be collected above-ground (Appendix A, Fig 2-2, pg. 141). Heating the soil also can encourage microbial growth which may speed the rate at which they break down the contaminant. The price range and effectiveness of this particular treatment varies according to length of time, concentration, air flow effectiveness, location, and depth to groundwater. A project in Castle Airport, CA indicated a price of $1.93/cubic yard for a passive bioventing system, but did not indicate the additional cost value for installing or maintaining the technology. Another indicated a cost of about $35/cubic yard for installation of the injection wells and the soil borings. Labor costs were $13.50/cubic yard if approached the same way.

*Bioremediation:*

Bioremediation is defined as the use of microorganisms, often in conjunction with supporting organisms such as plants or fungi, to break down organic contaminants (Fig. 2.2). This process occurs naturally in soil and water systems and has been proven extremely successful when using strains of bacteria specifically grown or selectively bred for this purpose. One of the first major design projects to use bioremediation is Gas Works Park (Seattle, WA) which utilized bioremediation and other mechanical processed to successfully remediate the soil. There are several types of bacteria developed to clean up petroleum oils, for instance, and have been used in situations such as ocean liner spills and diesel spills. The process can take from one-three months if conditions are appropriate. Many types of *Pseudomonas* bacteria have undergone development to encourage them to break down hydrocarbons. The application of these bacteria need to have some type of growing media or structure so in instances where they are needed in open water, fiber or root mats are used to grow full colonies in the area of contamination.

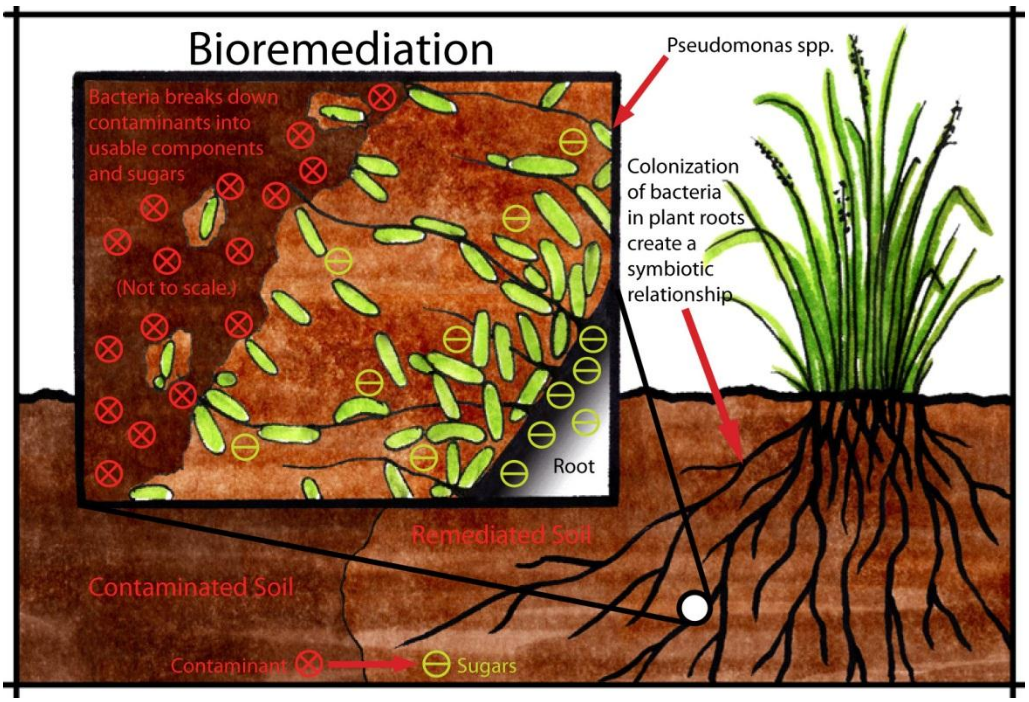


**Fig. 2.2.** Bioremediation process in soil

When used on the project site (*in situ*), the bacterial colonies will be encouraged to grow on and amongst the roots of certain types of grasses that show a successful symbiotic relationship in these situations. This process will be applied to the areas shown to have naphthalene contamination. The natural *Pseudomonas* in the soil will be encouraged to colonize on the root tips of the grasses installed in the contaminated areas, but if necessary more colonies could be introduced. The number of and concentrations of these “naphthalene degraders in the soil… varied across the site in relation to the distribution of the contaminants.” It is expected that without the contaminant to encourage growth in other areas, the bacteria will not over-colonize or spread uncontrollably past it (Ferguson, 2007). The cost of implementing this kind of remediation process varies depending on many factors including soil quality, climate conditions, and contaminant type.  However, the overall cost of implementation for different types of bioremediation decreases as the volume of treated soil increases. An average estimate places this kind of process at 60-70% the cost of other remediation technologies.

In a long-term projection of the effects the introduction of non-native soil bacteria would have on the indigenous strains and diversity of the site, studies have shown that after the initial colonization and growth while breaking down the contaminant, overall numbers of the introduced species will die back to a balanced soil organism diversity mix.  However, since many varieties of *Pseudomonas* and other degrading types of bacteria usually exist in most soils, the possibility exists that larger specialized colonies may not need to be introduced.  This project uses introduced varieties; however, it should be considered that "in soils affected by PAH contamination (e.g. after an oil spill) degrading potential of the indigenous soil bacterial community in the first phase should be exploited before the need to introduce a degrading strain or microbial consortium in a second phase is considered" (Gomes, 2005).

Bioremediation of methylene chloride was explored as a possibility for the project site; however, most studies were unsubstantial, inconclusive, or the process would not work with current site conditions.  Most cases studied used a *Pseudomonas* bacteria but only one that works in conjunction with grass roots.  The others were used to treat waste slurries, and the results were not sufficiently significant to use on site without more testing.

*Mycoremediation:*

Mycoremediation is the use of fungi to break down contaminants and is usually used to treat organic pollutants (Fig. 2.3). Most applications of this process are used to clean contaminated soils, but there are studies that show success in treating water (if grown on some kind of structure such as a coir log) and potential to even treat airborne pollutants. For the project site mycoremediation will be used to break down the aromatic hydrocarbons naphthalene and 2-methylnapthalene.

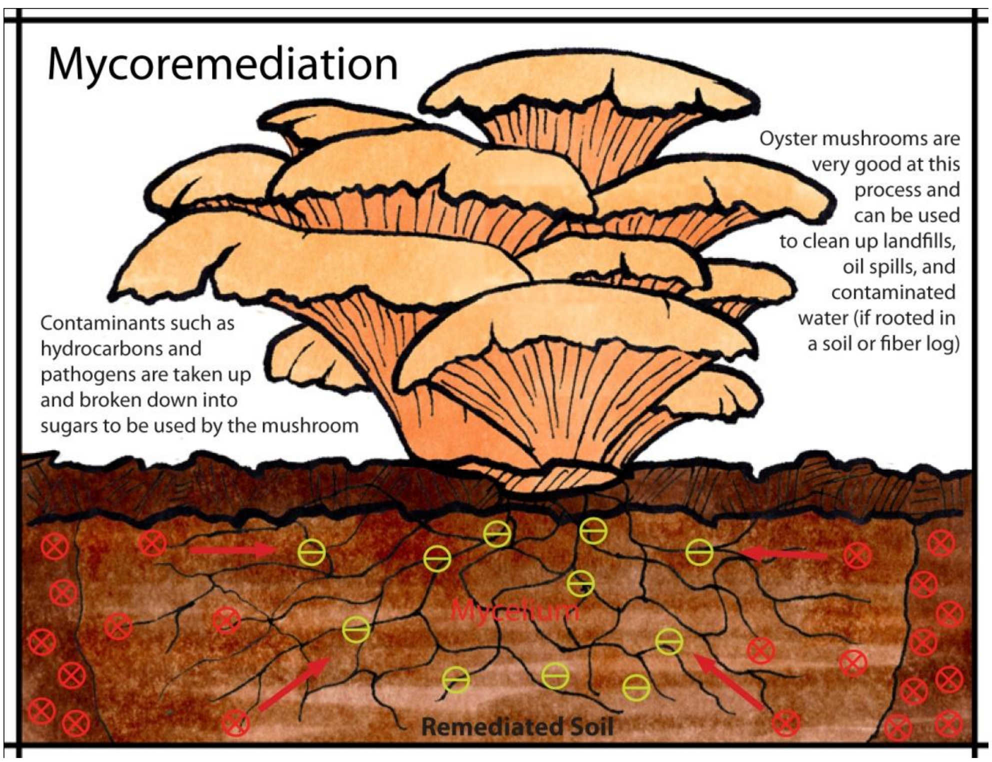


**Fig. 2.3.** Mycoremediation process in soil

If the soil of a site does not contain sufficient organic matter to support fungi, a growing medium such as wood chips or compost would be added to a contaminated area either in a layer on the surface or integrated in the soil. This would be seeded with the spawn of whatever species of mushroom is being used and conditions would be monitored and adjusted to encourage its growth. In one case in Bellingham, Washington, a variety of oyster mushroom

(*Pleurotus)* that was indigenous to the Seattle area was used to successfully break down diesel oil contamination along highways in a matter of 8 weeks. In this study, authors stated that due to the variable levels of contamination it is recommended to continue the process for at least a year depending on what test results indicate. The cost estimate was calculated as "under $50/cubic yard, including bulk fungal spawn and sawdust for inoculation, materials such as shadecloth covering, and the transportation, labor, and equipment for the application" (Thomas, 1998). Limited maintenance is needed for this process, other than periodic turning and reapplication of the sawdust or growing medium.

*Phytoremediation:*

Phytoremediation is the use of plant metabolism or growth to contain or remove contamination from soil or water (Fig. 2.4). Methods used are phytoextraction, phytodegradation, phytovolatilization, and phytostabilization (Appendix A, Table 2.12, pg. 141 through 2.15, pg. 143). The success or rate of remediation depends on what conditions are present and what type of plant is used, and benefits must be considered against potential problems (Appendix A, Fig 2-3, pg. 143 and Table 2-16, pg. 144).

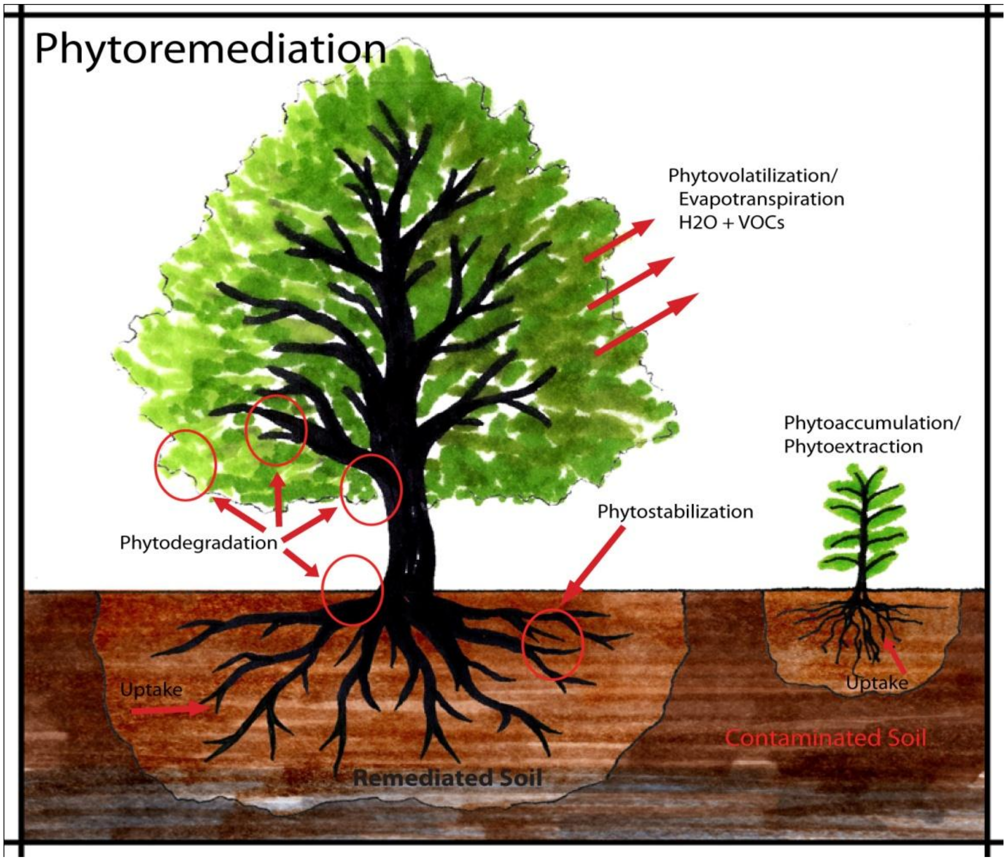


**Fig 2.4.** Phytoremediation processes in soil

*Phytoextraction:*

Phytoextraction is the primary method used in this project to deal with the heavy metal contaminants in the Peloquin site (Fig. 2.5). The metal is absorbed from the soil or groundwater by certain types of plants and stored in their roots, stems, or leaves. There are species of plants that are "hyperaccumulators", or types that naturally absorb above-average levels of the contaminants; these are particularly useful for phytoextraction. There are also varieties that successfully extract multiple types of heavy metals and can be reused in multiple situations. Examples include sunflowers and different types of mustards. The choice of the plant type used depends on a number of factors and should be carefully considered in relation to maintenance and possible invasiveness. (Appendix A, Fig 2-4, pg. 145)

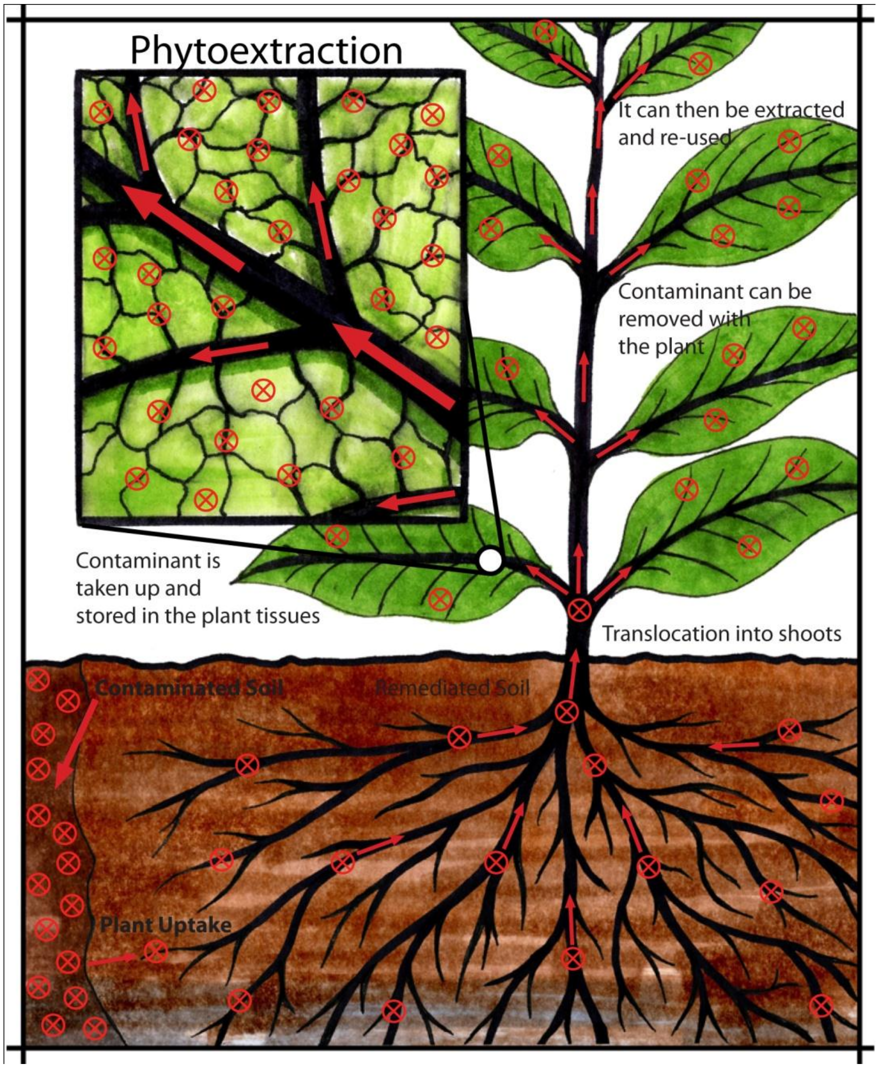


**Fig. 2.5** Phytoextraction process in soil

Once the metals have been stored in the above-ground plant tissue they are harvested from the site and disposed in a manner that is acceptable for the type of contaminant. The most significant practical issue with phytoextraction is the sheer volume of biomass to dispose of; depending on the type, may also need to be disposed as hazardous waste. Several projects have successfully dealt with this issue by incinerating the plant mass and sending the ash to certain companies that would be interested in extracting the metals. Zinc-laden mustard plants, for instance, have been taken by pharmaceutical companies to be recycled into raw materials for vitamins (Appendix A, Fig 2-5, pg. 145).

*Phytodegradation and Phytovolatilization:*

Phytodegradation is a process similar to bio- and mycoremediation, where the plant absorbs the contaminant and breaks it down into materials such as sugars to use as fuel, and releasing vapors in a process called phytovolatilization (Fig. 2.6). This process releases water vapors and other natural byproducts of the breakdown of the contaminant; however, it sometimes can be a process to avoid if the contaminant would become a harmful VOC. Many types of VOCs can break down in the atmosphere over time; however, they may have a negative impact on human health in the process or spread to other areas via wind and rain.

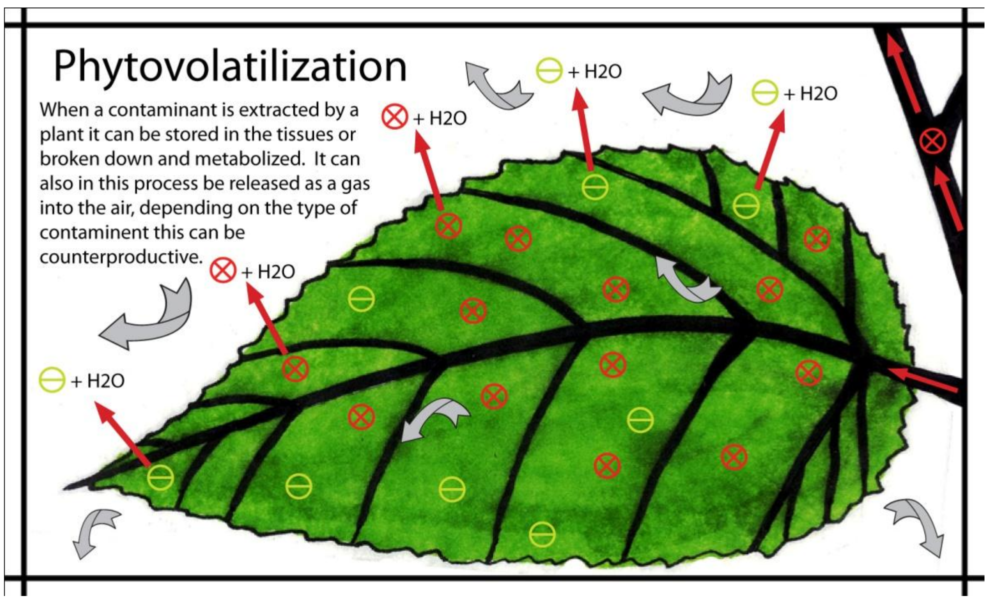


**Fig. 2.6.** Phytodegradation and phytovolatilization processes

Contaminant types in soil and groundwater need to be considered before planting anything that may extract and volatize them (Appendix A, Table 2-17, pg. 146).

*Phytostabilization:*

Phytostabilization is a process where soil is held in place by the roots of plants and prevented from moving due to groundwater migration (Fig. 2.7). The roots of the plants can extract contaminants as they pass through the soil, or in the case of willow or poplar tree, the water is absorbed by the tree at a fast enough rate that prevents the contaminant from leaving the site.

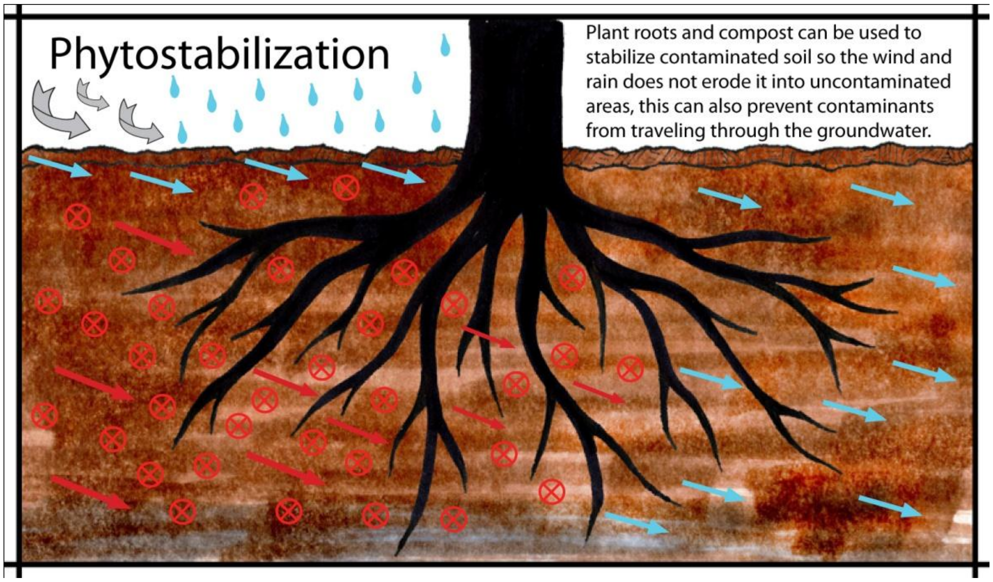


**Fig 2.7.** Phytostabilization process in soil

Tree root buffers, especially those using poplar hybrids, are successful on sites where the contaminant or groundwater does not extend deeper than 11 feet (Fig. 2.8). The roots have an average penetration depth of 18-23 feet; however, the area most impacted by the roots reflects an inverted cone and is more efficient toward the surface. This technique is often used to prevent effluent- or nutrient-laden soil and groundwater from spreading and contaminating other areas. Some projects using hybrid poplar growth have shown "substantial reductions in dichloromethane identified after the second growing season" (NATO, 2002) and reductions in other contaminants. The hybrid poplar used for phytoremediation projects is an extremely fast growing variety that can grow from five to eight feet/year and can reach a harvestable size in five to seven years. Cost of the trees will depend on whether whips or eight gallon potted plants are used. Whips, on average, are about $0.20/tree and are less expensive than the $8/potted tree, yet this will add a year or two to the harvestable date of the poplar trees in the buffers (Appendix A, Table 2-18, pg. 146).

- Greater than 25 species worldwide
- Fast growing ( 3 to 5 meters/year)
- High transpiration rates (100 liters/day optimally for 5 year old tree)
- Not part of food chain
- Trees can be used for paper production or as biomass for energy
- Long lived (25-30 years)
- Grow easily from cuttings
- Can be harvested and then regrown from the stump

**Fig. 2.8.** Advantages of *Populus sp*. in remediation (Chappell, 1997, pg. 6)

# CHAPTER 3 – INVENTORY AND ANALYSIS

## Site Location and History

*Location*

The project site (Fig. 3.1) is the Peloquin property at the intersection of McCulloch Rd and the Cardinal Greenway, directly south of the East Central Indiana Recycling plant, and north of the White River (Appendix A, Fig. 3.1, pg. 147).

The site consists of two parcels of land totaling 9.19 acres. The area around it is easily accessible by public transportation so the design process can be readily available for public use and participation. The proposed site is directly adjacent to McCulloch Park which provides standard park amenities such as open greens and sport fields. The site provides an opportunity for community involvement as it is located at the intersection of two branches of the Greenway. Neighborhood citizens and the Greenway enthusiasts can potentially use it. This park will help connect the adjacent parks along the Greenway: McCulloch Park, Craddock Wetland, and Minnetrista Park.

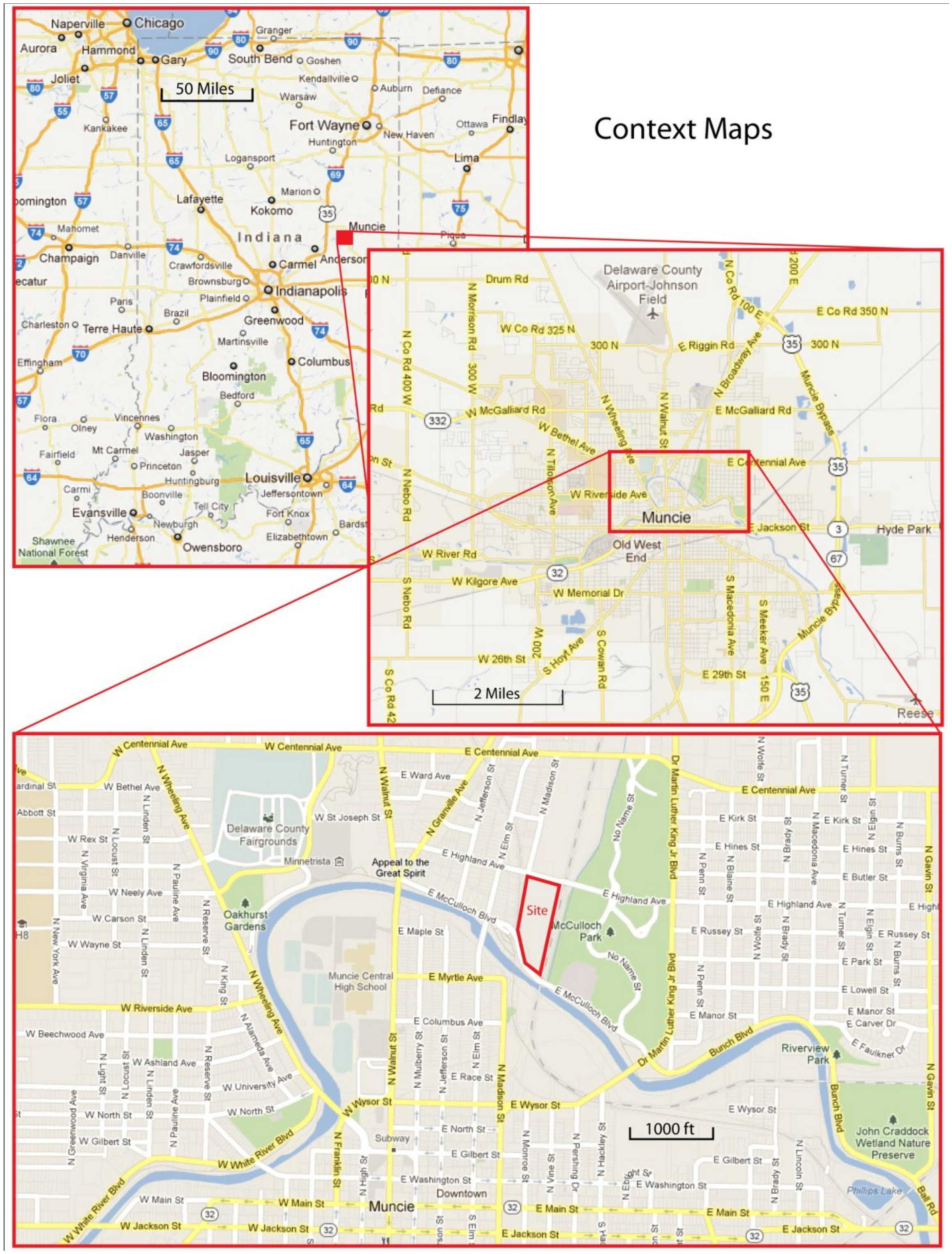


**Fig. 3.1.** Context Map: site is indicated in red within Muncie, Indiana

*Existing Site Conditions:*

The site shows the same characteristics as any long-abandoned lot in this part of Indiana. Although there are some mature trees along the edges of the property, these are primarily pioneering and opportunistic varieties, and much of the rest of the edge has been over-run by bush honeysuckle (*Lonicera maackii*) and other colonizing and invasive plant species. Various weeds and scrub species are thriving in areas where the soil has been disturbed, dumped with fill, or paved with gravel (Fig. 3.2).


**Fig. 3.2.** On-site Images: conditions showing weeds and debris (Symbiont, 2008, pg. 37-38)

*Site History:*

The Peloquin property was used as a dumping ground for furnace sand and slag by the Dayton Foundry, and subsequent foundries at the current site of the East Central Recycling Plant (Fig. 3.3). Much of the north part is composed of cinder gravel. The foundries and current recycling plant are located on the north side of E. Highland Ave., which creates the north boundary of the site. The 1896, 1902, and 1911 Sanborn maps show the foundry originally as the Whitely Malleable Castings Co. According to the 1950 and 1955 Sanborn maps the foundry ownership and name changed to the Muncie Malleable Foundry CO.; it changed again in 1965 map to the Dayton Muncie Mfg. Co. and was still present in the 1966 map (Appendix B, Fig. 1.1 - 7 for sequence of Sanborn maps, pg. 153-159).


**Fig. 3.3**. East Central Recycling, former foundry (Symbiont, 2008, pg. 38)

The northern part of the site housed an automobile maintenance shop as far back as 1896. It is unchanged in the 1911 and 1902 Sanborn map; however, the buildings in the 1950 map appear to be larger and are still present in the 1955 map. From then on both buildings disappear form the maps but there are still remnants of the paved and gravel parking areas located there. Not much is indicated regarding the southern portion of the property other than that it was left unused and is dominated by trees and undergrowth along the edges and scrub/weeds in the center.  The area may have been used to store scrap metal and parts.

On the east boundary of the site is FWC&L (Fort Wayne, Cincinnati and Louisville Railroad) north-south track, heading north to Hartford City, Bluffton, and Fort Wayne, and south to New Castle and Cincinnati. This track is still operational and services the many industrial facilities on its route.  The possibilities of some of the rail lines in Muncie becoming passenger lines are being explored; this line may be one which would provide opportunities for wider public access and interconnection.  Paralleling the far side of the tracks is a creek that flows south into the White River.

On the east side of the railway track is McCulloch Park (Fig. 3.4), donated to the city by George McCulloch in 1892, and at 118 acres it is currently one of the largest community parks in Muncie.  It was originally the site of another foundry and worker housing until it burned down. The park provides many sports-oriented amenities and outdoor activities, having a history of supporting professional and semi-pro baseball teams including the resident team, the *Muncie Fruit Jars*.

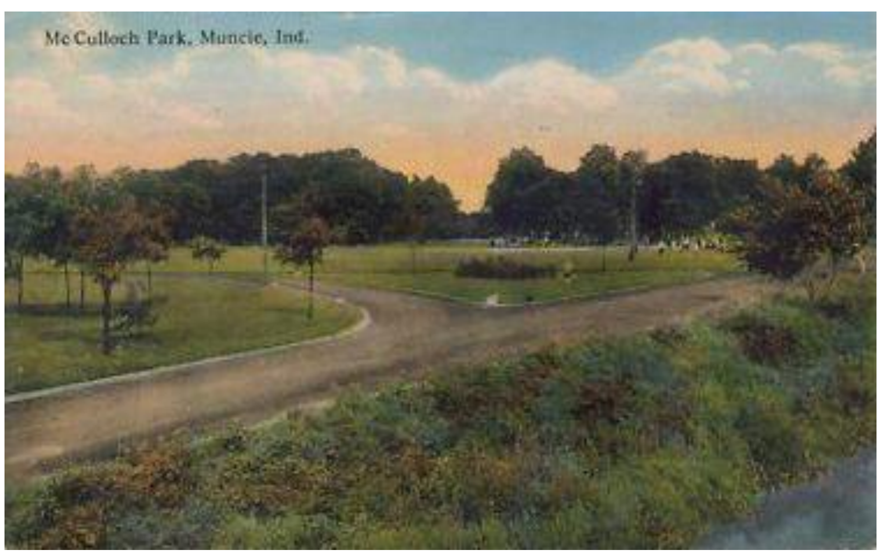


**Fig. 3.4.** Postcard; view of McCulloch Park from river (Addoway, 2012)

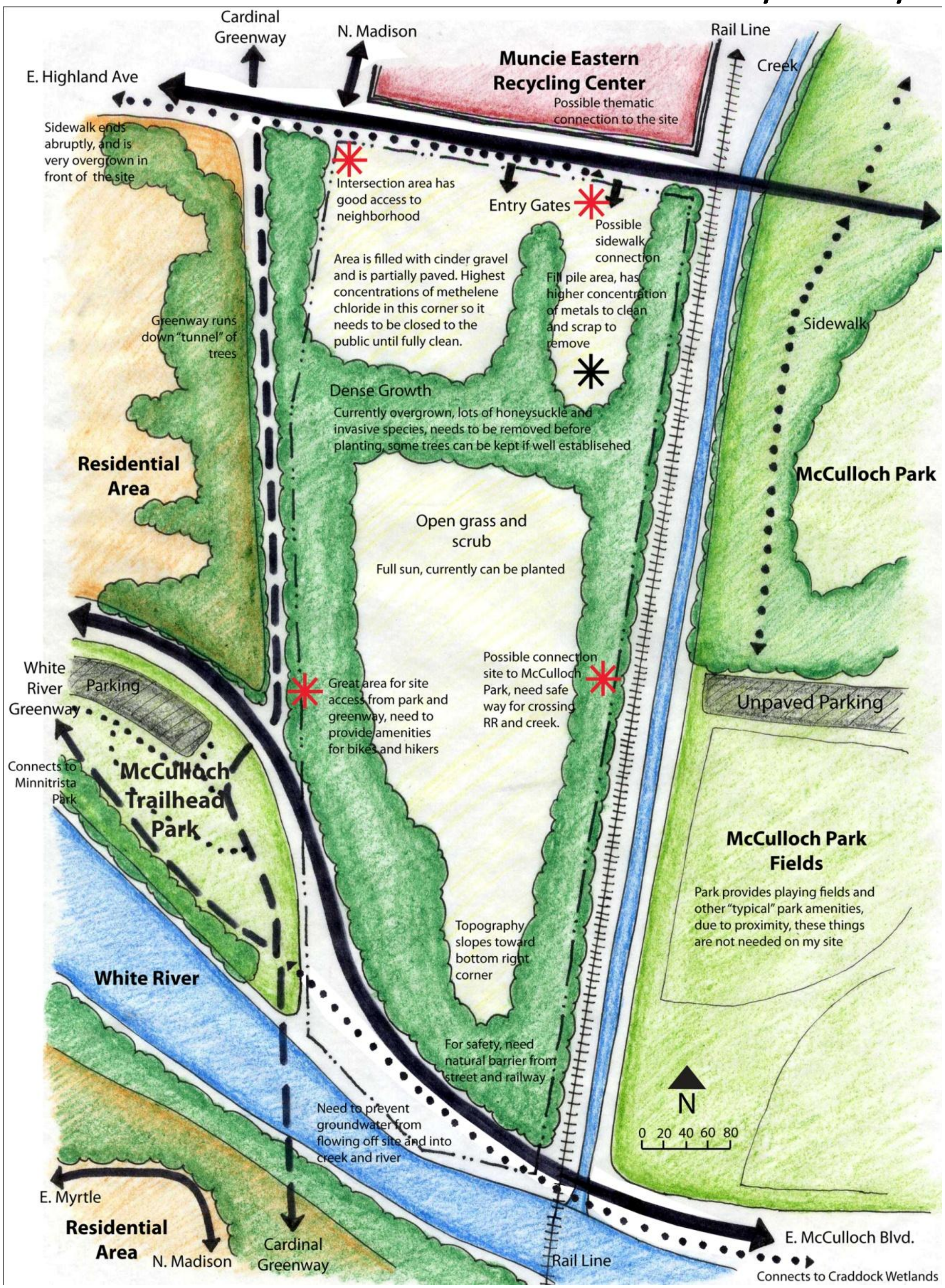


**Fig. 3.5.** Inventory and analysis of site and immediate context


**Fig. 3.6.** Site images of existing conditions along south and east border

To the south of the site (Fig. 3.5) is E. McCulloch Blvd. following the upper curve of the White River.  This is a short section of road, ending at the intersection by the Minnetrista Cultural Center and becoming Bunch Blvd. after it passes the east border of McCulloch Park. The street is narrow and in poor condition.  There is also sidewalk access only on the far side of the road when passing the site. It passes under the railway bridge that crosses the river at a sharp curve, which severely limits visibility, but the road is not heavily trafficked so pedestrian safety has not been a concern there (Fig. 3.6).

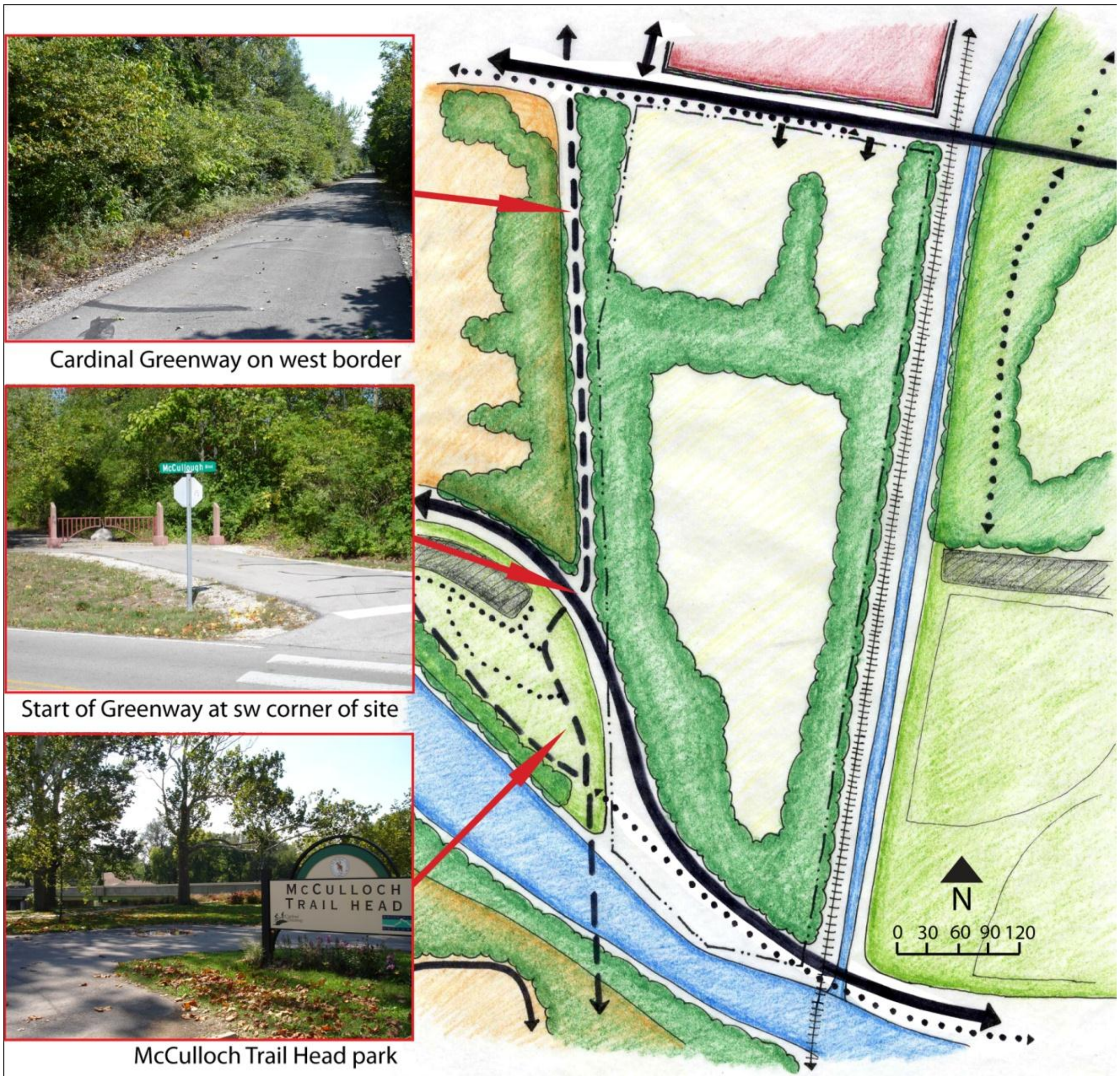


**Fig. 3.7.** Site images of existing conditions along south and west of site

The Cardinal Greenway connects the south side of Muncie to the north at this point and creates the western border of the site (Fig. 3.7). Directly on the south side of the river following this trail there is the Greenway Pocket Park. The trail then crosses over a bridge located to the southwest of the site, intersects the White River Greenway at the McCulloch Trailhead Park, and the Cardinal Greenway continuing north. Farther to the west the White River Greenway passes through Minnetrista Park.  Following to the east it continues by another park located to the southeast, the Craddock Wetlands. The trailhead park provides a scenic view of the river and parking for people using the greenway.

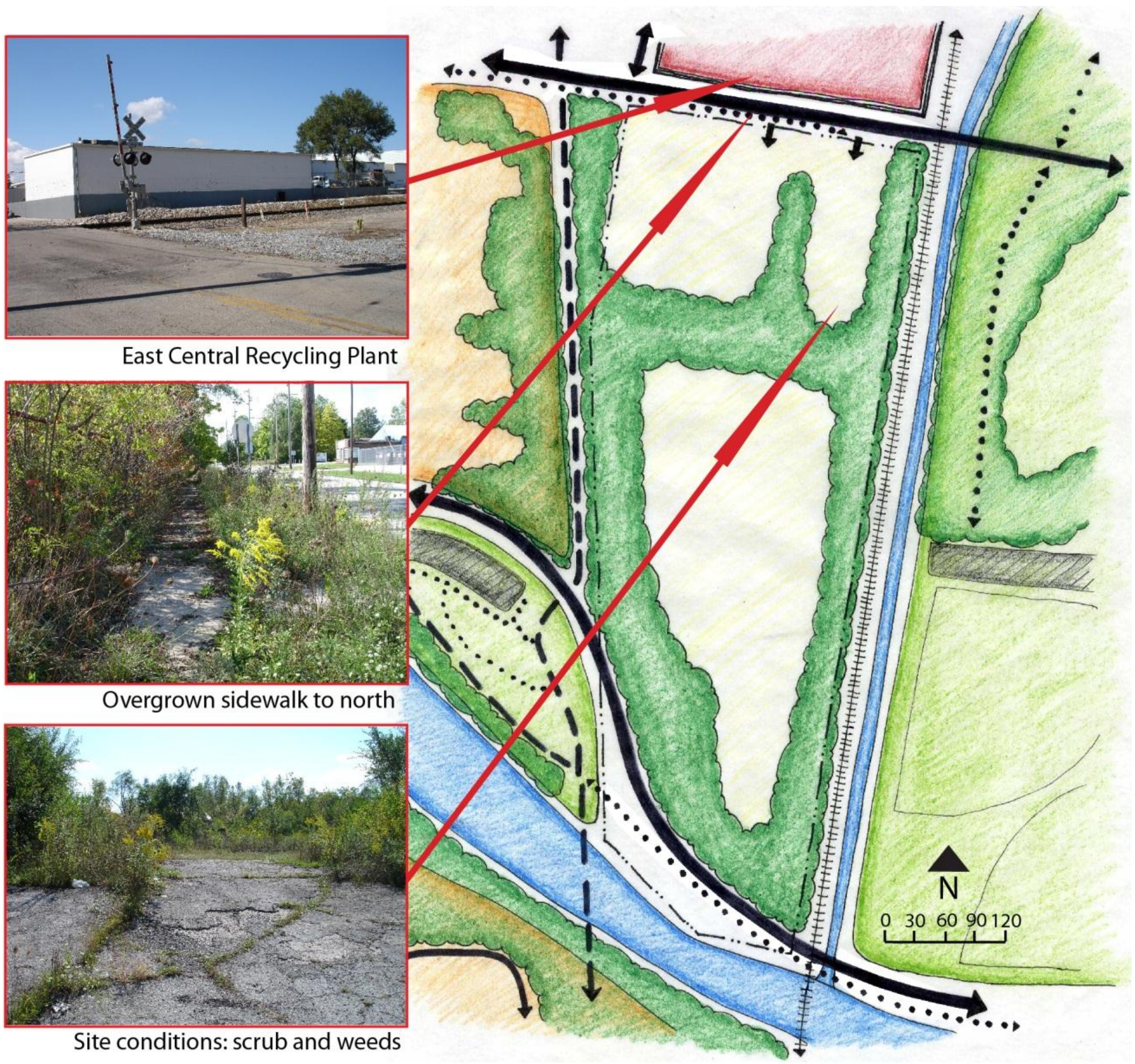


**Fig. 3.8.** Site images of existing conditions on-site and along north border

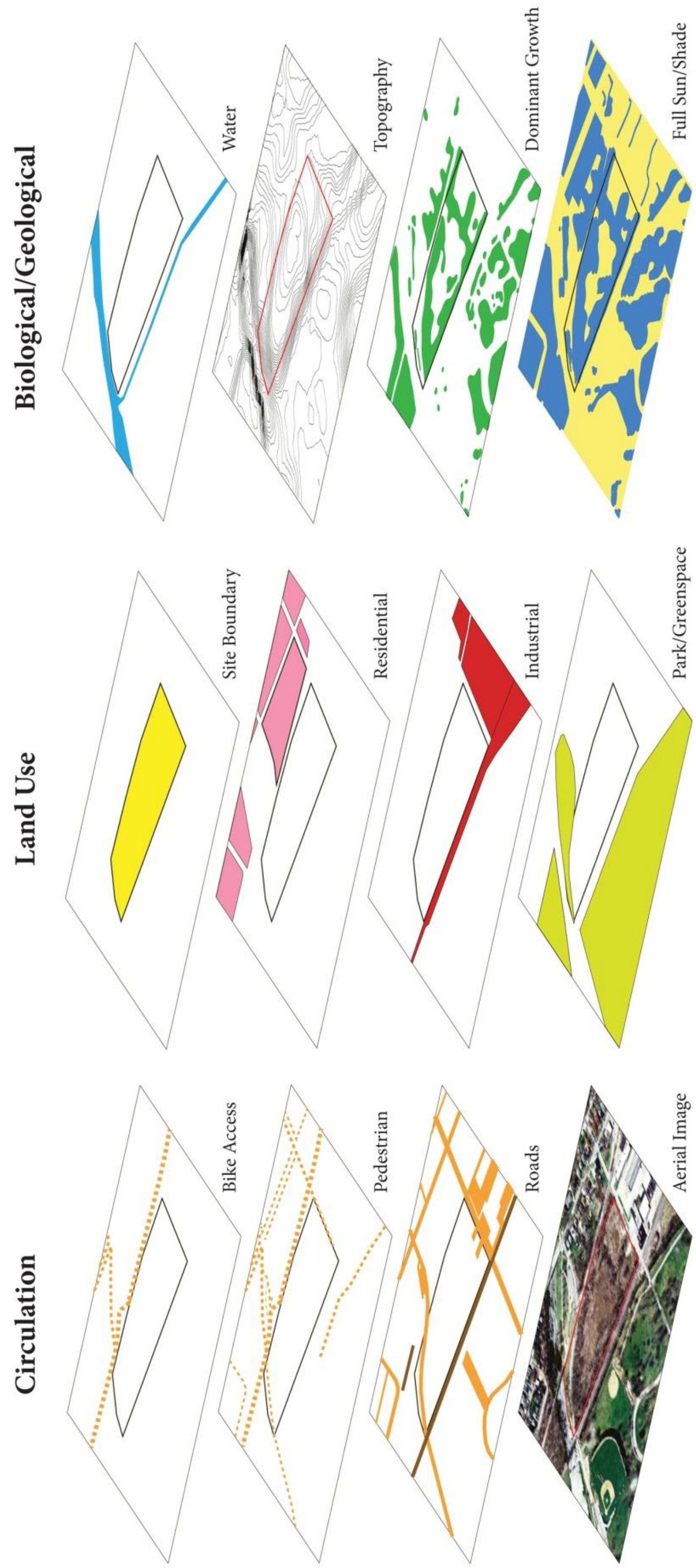


**Fig. 3.9.** Diagram of site inventory

A residential neighborhood composed of standard single-family lots is located on the west border on the other side of the Cardinal Greenway. It is a family-based neighborhood that is showing the same signs of economic decline found in the rest of the city. Many homes are in need of repair; other properties are for sale and appear abandoned and in severe disrepair and the streets and sidewalks are showing signs of decay (Fig. 3.10). The green spaces for each property seem to be reserved for lawns and play areas for children and there appears to be limited public garden areas in this neighborhood.

**Fig. 3.10.** Images of residential area to west of site

## Brownfield Assessment

*Contaminants:*

According to the Phase 1 Environmental Assessment prepared for the city of Muncie (Symbiont, 2008), several contaminants were indicated in soil tests (Appendix A, Fig. 3.2, pg. 148). Contaminants tested for included heavy metals, VOCs (volatile organic compounds) and BNAs (base neutral acids). Contaminants identified include those expected from automobile and metal manufacturing: heavy metals, aromatic hydrocarbons, and chlorinated solvents, all of which occur in soil or groundwater. Of those tested for, three were found above legal residential levels on the Peloquin site: methylene chloride, chromium, and naphthalene.

Contaminants below residential levels, yet high enough for concern in other areas, were chromium, lead, nickel, and zinc. Minimal or trace contaminants included beryllium, copper, mercury, and phenol; 2-methylnaphthalene was found at fairly high levels yet legal levels were not provided. Concentrations above legal residential levels are indicated in orange, while contaminants of concern that are below legal limits but still addressed in the design are indicated in yellow. The report does not specify if the form of the chromium is III or VI, so areas with high contamination will need to be isolated in case it is form VI or oxidizes into VI from form III.

The project site should have a full assessment conducted for soil and groundwater contaminants, but for this design project the soil and contamination diagrams are based on the series of tables (Figs. 3.11-3.13) included in the Phase I Environmental Site Assessment (Symbiont, 2008).

| Fill Piles Analytical Results<br>Peloquin Property<br>Muncie, Indiana | | | | | | |
|---|---|---|---|---|---|---|
| | | | | | RISC Default Closure Levels | |
| Sample I.D. | Grab-1 | Grab-2 | Grab-3 | Duplicate Grab-1 | Residential | Commercial/ Industrial |
| Metals (mg/kg) | | | | | | |
| Phenol | 3.6 | 2.8 | 0.82 | 2.7 | 110 | 320 |
| Beryllium | ND | ND | ND | 0.5 | 63 | 2,300 |
| Chromium | 23.9 | 8.1 | 62.9 | 38.1 | 38 | 120 |
| Copper | 42.2 | 12.6 | 90.2 | 48.6 | 580 | 1,700 |
| Lead | 28.6 | 9.9 | 13 | 26.4 | 81 | 230 |
| Mercury | 0.021 | 0.019 | 0.027 | 0.028 | 2.1 | 32 |
| Nickel | 13.5 | 4.5 | 47 | 11.9 | 950 | 2,700 |
| Zinc | 47.9 | 44.8 | 26.6 | 39.2 | 10,000 | 10,000 |
| VOCs (ug/kg) | | | | | | |
| Methylene Chloride | ND | 32* | ND | 42* | 23 | 1,800 |
| Naphthalene | ND | 800 | ND | ND | 700 | 170,000 |
| BNAs (ug/kg) | | | | | | |
| 2-Methylnapthalene | 720 | 1100 | 910 | ND | NA | NA |

* indicates analyte was also found in the method blank
ND - Not detected above the laboratory reporting limit
NA - Not available

**Fig. 3.11.** Results of fill pile tests (Symbiont, 2008, pg. 194)

The foundry fill piles in the north show naphthalene and chromium levels above the Risk Integrated System of Closure, Default Closure Levels (RISC, DCLs) for residential land use, and metal debris are scattered in the foundry sand and immediate area (Fig. 3.11). The existence of other hidden fill piles across the site are a possibility, but the brownfield assessment does not have that level of detail. If extensive testing is conducted for the site, a more accurate representation of the levels and extent of the contaminants would be available.

| Groundwater Analytical Results<br>Peloquin Property<br>Muncie, Indiana | | | | |
|---|---|---|---|---|
| | | | RISC Residential Default Closure Level | |
| **Sample I.D.** | **G-5** | **Equipment Blank** | **Residential** | **Commercial/ Industrial** |
| Sample Depth (ft) | 8 | NA | | |
| **Metals (mg/L)*** | | | | |
| Antimony | 0.0018 | ND | 0.006 | 0.041 |
| Nickel | 0.0071 | ND | 0.0083 | 2.0 |
| **VOCs** | ND | ND | NA | NA |
| **BNAs** | ND | ND | NA | NA |

ND - Not detected above the laboratory reporting limit
NA - Not available

**Fig. 3.12.** Groundwater test results (Symbiont, 2008, pg. 193)

Groundwater tests show only two metals: antimony and nickel. This project considers only nickel for remediation as antimony occurs at trace levels (Fig. 3.12).

| Soil Analytical Results<br>Peloquin Property<br>Muncie, Indiana | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | RISC Default Closure Levels | |
| **Soil Boring I.D.** | **G-1** | **G-2** | **G-3** | **G-4** | **G-5** | **G-6** | **Residential** | **Commercial / Industrial** |
| Sample Depth (ft) | 18-20 | 12-14 | 4-6 | 4-6 | 6-8 | 6-7.5 | | |
| **Metals (mg/kg)** | | | | | | | | |
| Cyanide | ND | ND | ND | ND | ND | ND | 150 | 410 |
| Phenol | 0.96 | 0.37 | 0.19 | 1.7 | 1.9 | 0.94 | 110 | 320 |
| Beryllium | ND | 0.4 | 0.4 | 0.4 | ND | ND | 63 | 2,300 |
| Chromium | 7.9 | 10.8 | 10.2 | 8.8 | 10 | 7.3 | 38 | 120 |
| Copper | 13.7 | 9.2 | 8.4 | 12 | 74.2 | 12 | 580 | 1,700 |
| Lead | 5.9 | 8.7 | 7.9 | 9.2 | 23 | ND | 81 | 230 |
| Mercury | 0.021 | 0.029 | 0.027 | 0.017 | 0.033 | 0.011 | 2.1 | 32 |
| Nickel | 16.2 | 10.4 | 9.34 | 12.7 | 13 | 14.9 | 950 | 2,700 |
| Zinc | 38.9 | 46.5 | 39.3 | 34 | 35.1 | 32.3 | 10,000 | 10,000 |
| **VOCs (ug/kg)** | | | | | | | | |
| Methylene Chloride | ND | ND | ND | 28 | 38* | 120* | 23 | 1,800 |
| **BNAs (ug/kg)** | | | | | | | | |
| Acenaphthene | ND | ND | ND | ND | ND | ND | 130,000 | 1,200,000 |
| Anthracene | ND | ND | ND | ND | ND | ND | 51,000 | 51,000 |
| Benzo (b) anthracene | ND | ND | ND | ND | ND | ND | NA | NA |
| Benzo (b) fluoranthene | ND | ND | ND | ND | ND | ND | 5,000 | 15,000 |
| Benzo (k) fluoranthene | ND | ND | ND | ND | ND | ND | 39,000 | 39,000 |
| Benzo(a) pyrene | ND | ND | ND | ND | ND | ND | 500 | 1,500 |
| Benzo (ghi) perylene | ND | ND | ND | ND | ND | ND | NA | NA |
| Carbazole | ND | ND | ND | ND | ND | ND | 5,900 | 20,000 |
| Chrysene | ND | ND | ND | ND | ND | ND | 25,000 | 25,000 |
| Fluoranthene | ND | ND | ND | ND | ND | ND | 880,000 | 880,000 |
| Fluorene | ND | ND | ND | ND | ND | ND | 170,000 | 1,100,000 |
| Indeno (1,2,3-cd) pyrene | ND | ND | ND | ND | ND | ND | 3,100 | 3,100 |
| 2-Methylnapthalene | ND | ND | ND | ND | ND | ND | NA | NA |
| Phenanthrene | ND | ND | ND | ND | ND | ND | NA | NA |
| Pyrene | ND | ND | ND | ND | ND | ND | 570,000 | 570,000 |

* indicates analyte was also found in the method blank
ND - Not detected above the laboratory reporting limit
NA - Not available

**Fig. 3.13.** Soil boring test results (Symbiont, 2008, pg. 191)

The soil borings conducted on-site show the presence of heavy metals (Fig. 3.13). These were below RISC DCLs; however, they are high enough for concern and are addressed in the remediation process (Fig. 3.14). Methylene chloride was detected in multiple borings but is indicated as a laboratory artifact except in the G4 boring in the northeast corner. The other possible contaminants tested for were not found in any measurable quantities.

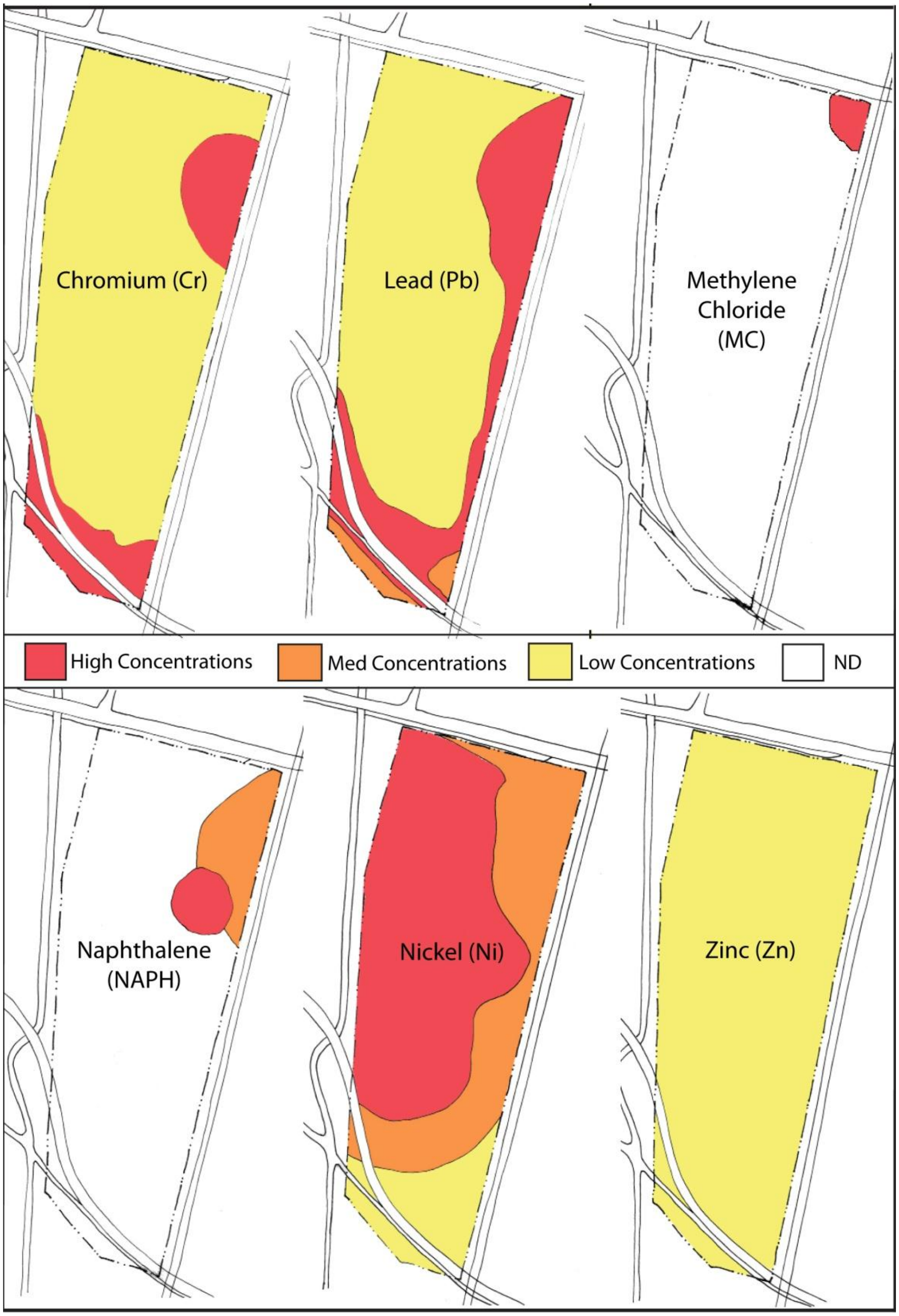


**Fig. 3.14.** Concentration diagrams for contaminants of concern

*Soil Characteristics:*

Soil cross-sections across the site indicate a relatively shallow bedrock and soil types indicative of the northern Indiana geo-soil profile (Fig. 3.15). The bedrock material is limestone and ranges from 6-20' depth. The northern and southern parts of the site have a greater variety of soil types, and the northern and southern-most borings are only a maximum 7.5' depth. The most common soil type located directly above the bedrock is a moist brown or sandy silty clay with trace gravel. The soil depth is generally shallower at the very north and south of the site, and as thick as 14' in the center. The layer above that, depending on the location, is composed of clays with gravel or sand with gravel, greater amounts of cinder gravel and brick fragments toward the surface. Groundwater was indicated at an eight foot depth.

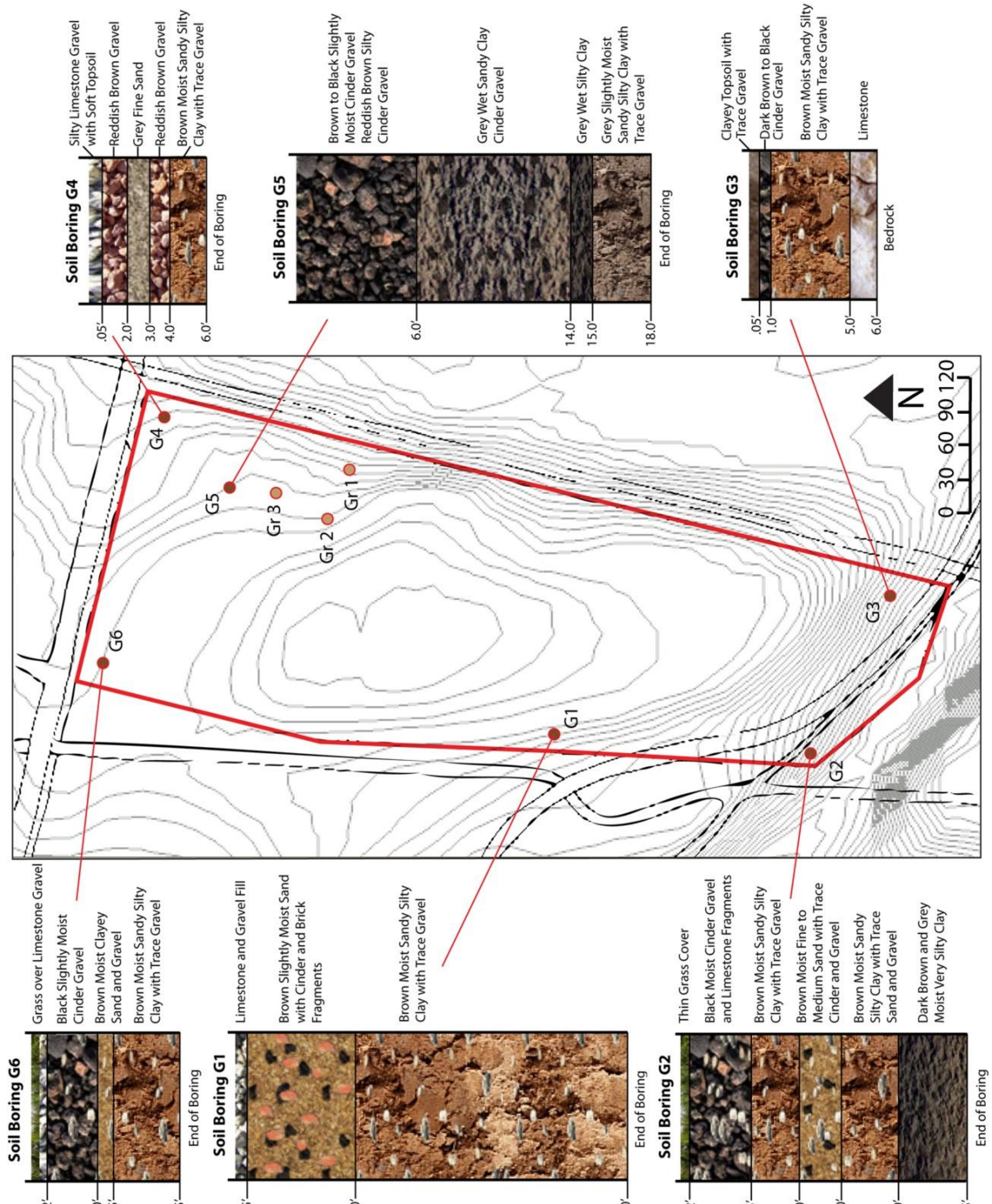


**Fig. 3.15.** Soil boring cross-sections with depths and soil types

These soil types will affect the way groundwater flows through the site, surface water infiltrates, and roots penetrate. Areas that are predominately cinder gravel such as in the northern part will infiltrate faster and will need to be isolated to prevent contaminant migration

(Fig. 3.16). The surface soil is characterized as primarily "Fox: UenB", in the north-east corner where there is methylene chloride, the soil type is indicated as "Urban lan: UfuA"; both surface soils are well-drained, shallow sloped, urban soil mixes.

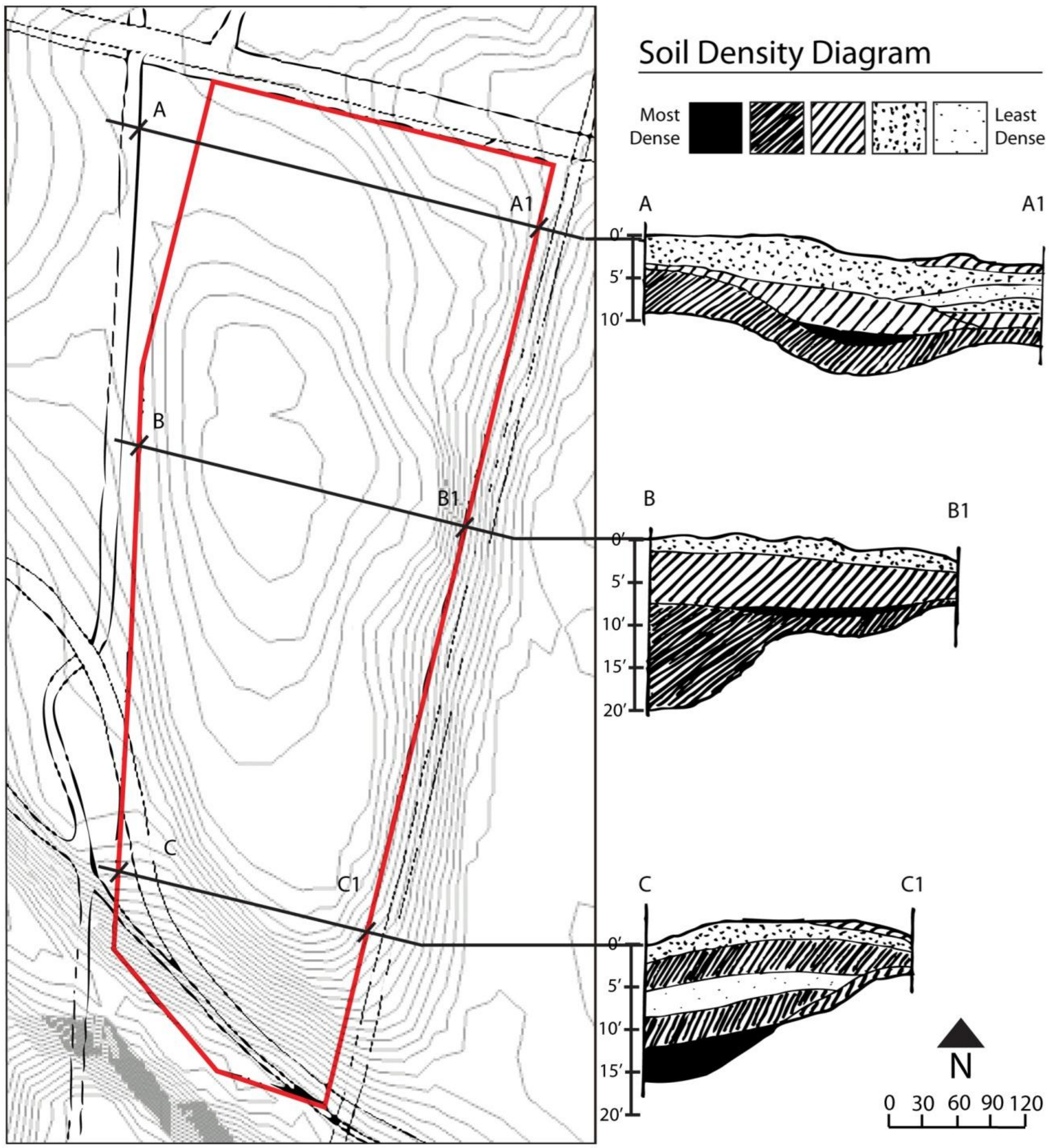


**Fig. 3.16.** Soil density sections indicating soil depth and higher or lower permeability

The layer closest to the bedrock is less permeable than the upper surface layer.  There is also a denser clay layer in the center of the site.  These layers may help prevent surface water and groundwater from moving through the site and leaching contaminants out of the soil and into the surrounding area.

### Context Inventory and Analysis

The Phase I Environmental Site Assessment (Symbiont,2008) included an analysis conducted by Environmental Data Resources Inc. with Geocheck (EDR) Radius Maps, of past activities that could be potential off-site contamination sources  or liabilities.  An inventory and analysis of the larger context of the site in relation to outside contamination or influences show that potential off-site contamination sources are far enough away and of a contaminant type that does not elicit any immediate concerns.  The East Central Recycling Center and adjacent railway tracks are the only sources that may have an impact on the site, but they are not documented as actively doing so (Fig. 3.17).   Potential sources that are of a higher elevation than the site are indicated with red dots on the EDR Radius Maps.

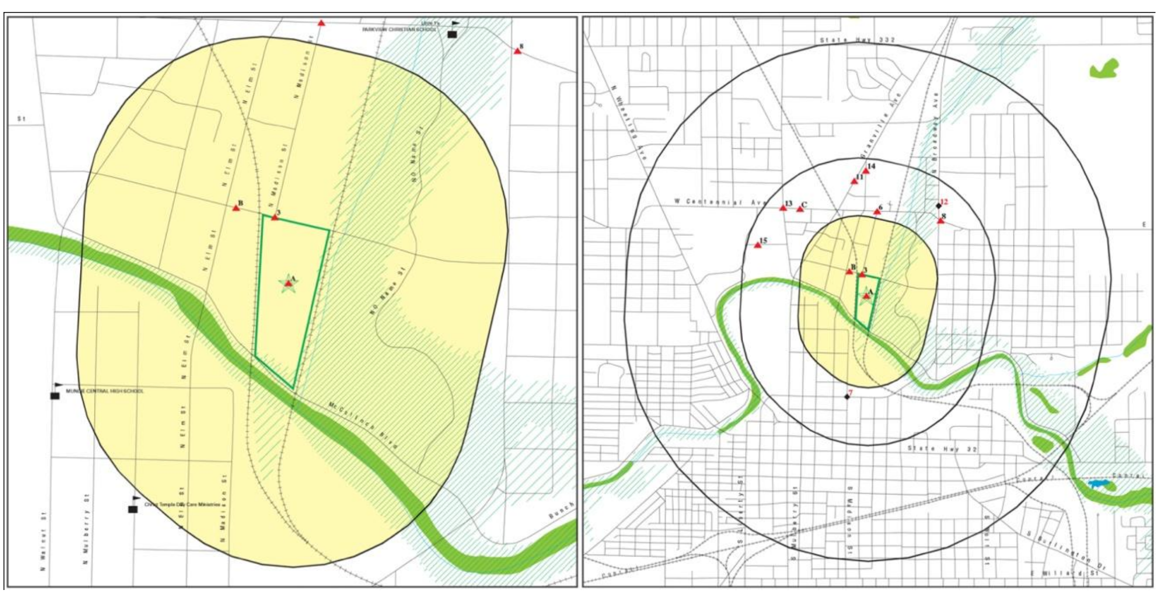

**Fig. 3.17.** EDR Radius maps of off-site contamination sources within ¼-to a ½-mile distance
(Symbiont, 2008, pg. 90-91)

# CHAPTER 4 – CASE STUDIES

Case studies are an excellent source for design inspiration. With many brownfield projects the design is very basic with remediation as the only goal. These projects are usually isolated from public use or view, as aesthetic and public interests during the process are not a primary concern. The following are completed or ongoing projects dealing with soil and water remediation, not just as a means but also as an interactive process for landscape design.

## Case Study 1: Fresh Kills Park: New York, NY

*The Site:*

The Fresh Kills Park is an ongoing brownfield remediation design project located on the south part of Staten Island and is owned by New York City. The design is based on the winning project, "Lifescape," of the international Design Competition proposed by the city (Fig. 4.1). It focuses on redesigning a former household waste landfill into a safe, open public park. An interdisciplinary design team *Field Operations* began the project in 2003. The site is 2,200 acres, roughly 2.5 times the size of Central Park and is expected to reach conclusion in 2035.

**Fig. 4.1.** Master Plan of Fresh Kills Park, New York, NY (Freshkills Park, 2012)

Fresh Kills was a landfill built in 1948 on Staten Island. It is latticed by several creeks such as the Little and Great Fresh Kill, and rests within the floodplain of the Arthur Kill that empties into the Upper, Lower, and Raritan Bays (Fig. 4.2). The site was originally comprised of open fields, wetlands, and creeks before it was used as a landfill for household wastes. It was closed in 2001 but was temporarily re-opened following the September 11, 2001 Twin Towers disaster to serve as a sorting ground for the rubble, much of which is still buried there today.


**Fig. 4.2.** Site in context of Staten Island and birdseye perspective of design (Freshkills Park, 2012)

Approximately 45% of the park space at the beginning of the design process was comprised of landfill and the rest is wetland and field space (Fig. 4.3). A phased remediation plan was developed to address the individual levels of contaminations in different parts of the site, and to regulate public access to these areas until the various sites are safe enough for full use. Contaminants included anything normally found in landfill debris, which travels primarily in the form of heavily contaminated leachate, or leaking gasses such as methane which are released as the fill contents break down.

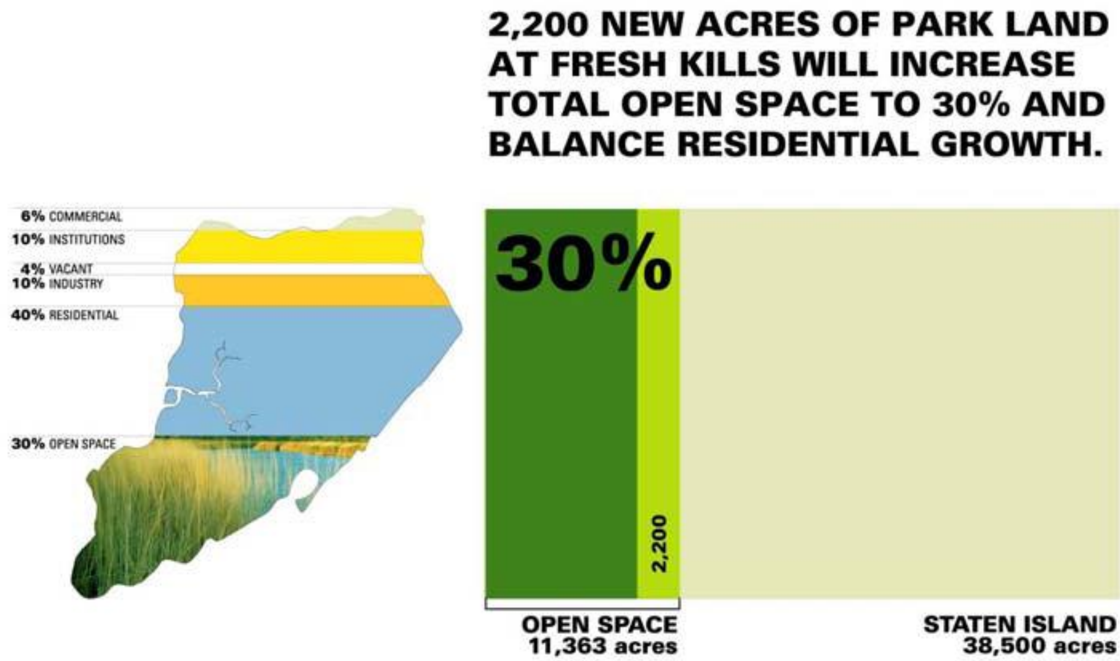


**Fig. 4.3.** Park Land Use in proportion to space available on Staten Island (Freshkills Park, 2012)

*Design Process:*

Much of the larger debris was moved to a specific area of the site and the areas with rubble were developed as a 9/11 memorial area. Large areas were capped with an impermeable layer to trap the leachate and treat it using phyto-, myco-, and microbial-remediation techniques. This barrier also is able to trap the gasses released by the landfill before they enter the atmosphere. The gasses are harvested from the capped areas and reused as fuel. The quantities collected have produced, on average, enough energy for about 22,000 homes annually. The excess is sold to energy utilities thus earning the city $12 million in extra revenues. A phased development plan was created to gradually incorporate the entire site, public access, and proposed uses (Fig. 4.4). Many different activity centers are part of the design, including sports fields, boat access, skiing and hiking trails, bird overlooks, environmental trails and parks, alternative energy demonstrations, restaurants, and many other amenities.


**Fig. 4.4**. Park Zones and public access (Freshkills Park, 2012)

*Design Relevance:*

The phased process and timeline developed for Fresh Kills serve as an excellent design source and method for tackling similar problems on the Peloquin property (though the former project is at a much larger scale). The phases directly address designing for and allowing public access to different areas of the park based on decreasing levels of soil and groundwater contamination, while also focusing on circulation and environmental restoration in response to the clean-up process (Fig. 4.5). The combination of a community park and environmental restoration project aligns well with the Peloquin project goals. The graphic representation of the phased implementation also suggests an effective method for documenting the project.

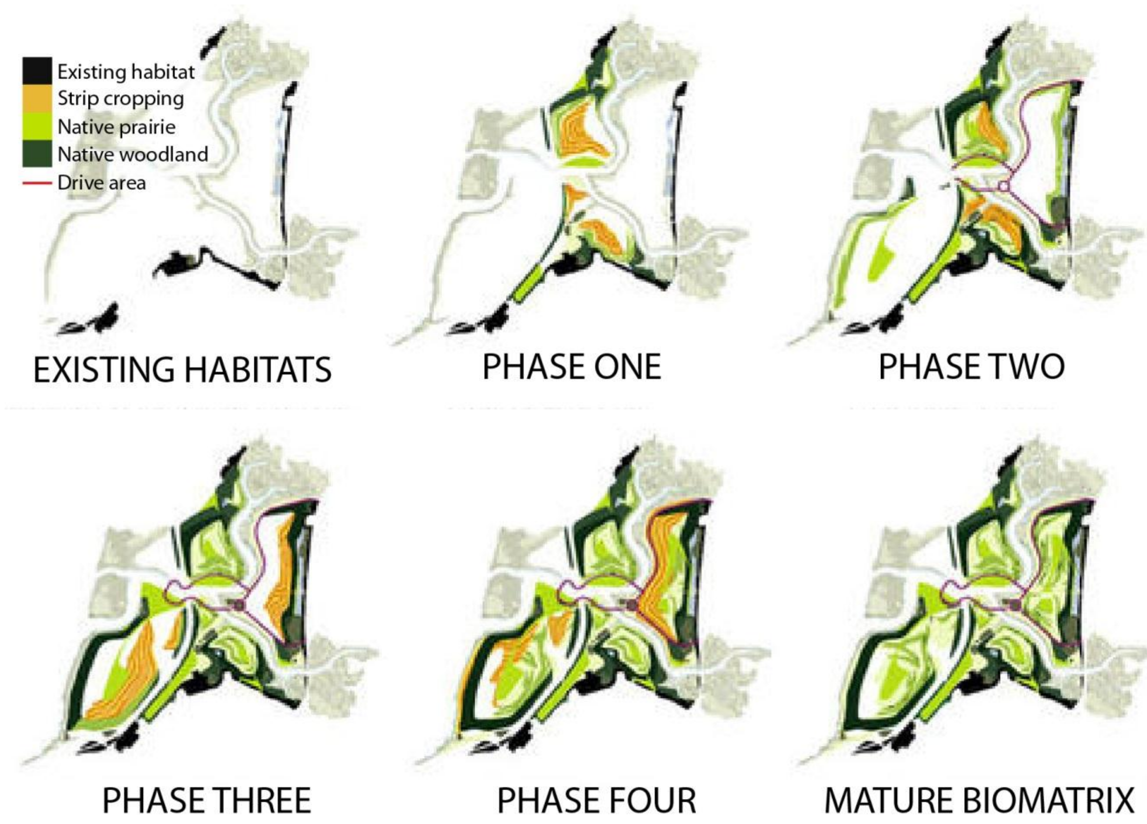


**Fig. 4.5.** Diagram adapted from master plans of phased new habitat cultivation

## Case Study 2: Landschaftspark: Duisburg Nord, Germany

*The Site:*

Once a coal and steel blast furnace, this brownfield site in Germany is now a 570-acre public park (Fig. 4.6). The designer, Peter Latz+ Partner, utilized the existing site structures as part of their inspiration, while incorporating other site scrap materials in the design. The area around the park was densely populated and the landscape itself was disorganized from frequent economic upheavals and developmental changes. The site and surrounding environment were extremely polluted with heavy metals, polyaromatic hydrocarbons, and debris left over from coal and metals foundries.


**Fig. 4.6.** Plan view of park (Co-tain, 2012)

*Design Process:*

Rather than removing the structures and contaminated soils, the designers utilized them in ways that encouraged public use, and used phytoremediation to bring the soils back to safe public-use levels.  Heavily contaminated ore bunkers were transformed into gardens, their sides becoming climbing walls (Fig. 4.7).  Old casting mold covers create a large geometric open plaza emphasizing the building materials and its pattern of corrosion, a catwalk by the sintering plant provides an excellent viewing platform, and the cooling tanks store and treat stormwater.

**Fig. 4.7.** Overview of park shows existing structures and grid layout of ore bunkers (Co-tain, 2012)

The gardens are impressive and include a plaza full of flowering trees that echo the geometric patterns of the ore bunkers and lines of the site structures, and the "natural" and designed plantings reference how plants were used to break down contaminants left by the industries (Fig. 4.8).

**Fig. 4.8.** Stormwater retention pools and ore bunker converted into a climbing wall (Co-tain, 2012)

*Design Relevance:*

This project used the history and existing site conditions to influence the overall design. It is not just a public park that was once a brownfield, but a park that celebrates its history and the journey it made to become usable public space (see Fig. 4.9). This project illustrates how the history and/or the buildings and materials present on a site can be used to create the layout, or at least influence its design as shown with the grid format concept/design.

Fig. 4.9. Plaza in bloom and an ore bunker formal garden (Co-tain, 2012)

## Case Study 3: Tianjin Qiaoyuan Wetland Park: Tianjin,China

*The Site:*

The Tianjin Qiaoyuan Wetland Park is located in Tianjin, China next to a large, densely populated informal housing area surrounded by housing units, temporary structures, a large highway, and an overpass. The project site was a 54-acre shooting range, garbage dump, and drainage sink for the city's urban stormwater. It was re-designed in 2008 by Turenscape into a public wetland park that functioned to clean the site soil and the water flowing from the city (Fig. 4.10). The site was heavily polluted, littered, and deserted, and since it was originally wetlands and salt marshes the soil is saline and alkaline, which makes it difficult to grow many types of plants. The people living in the area were also severely disadvantaged economically.

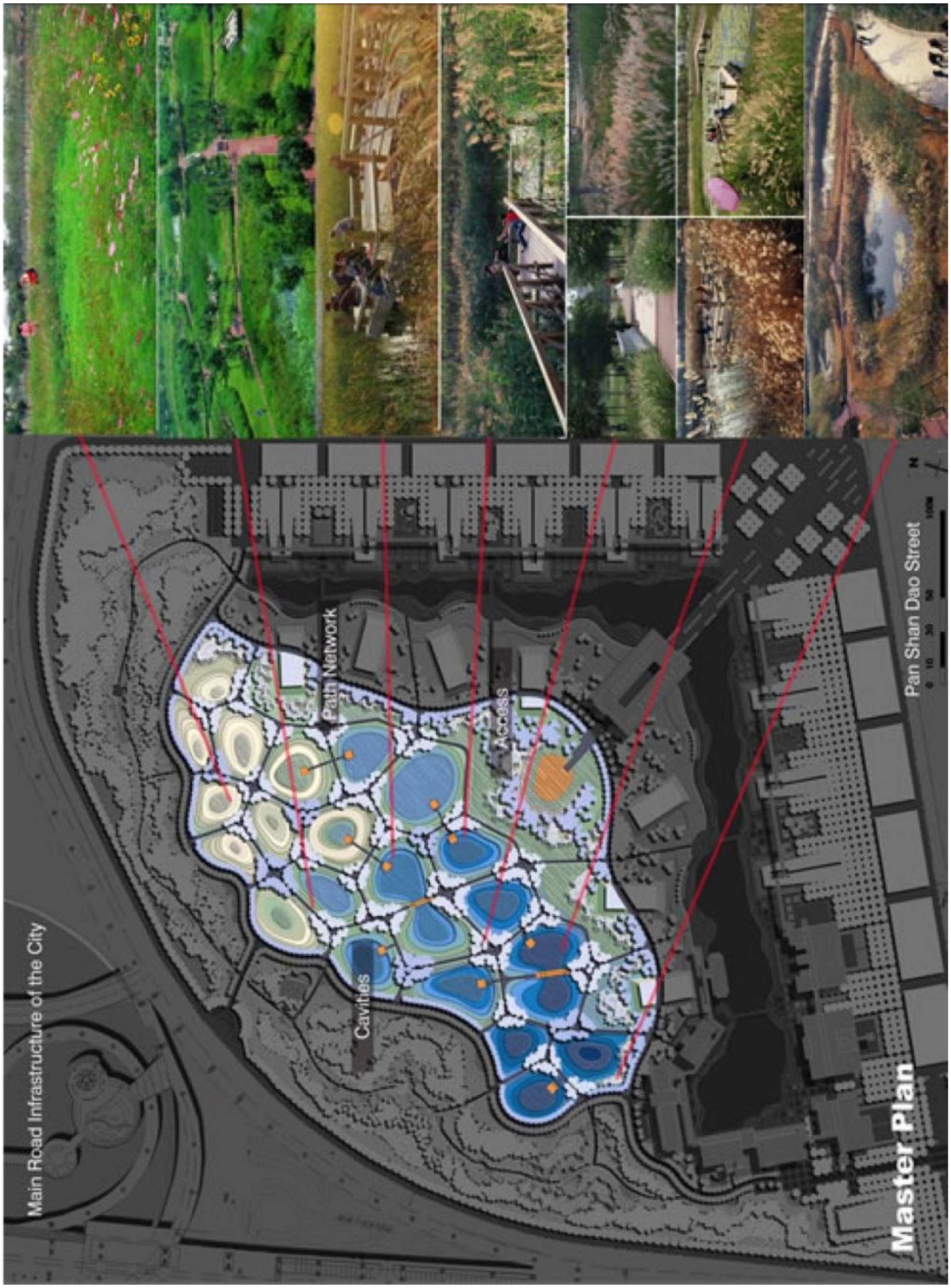


**Fig. 4.10.** Site plan and corresponding views (YouthLA, 2010)

*Design Process:*

The project is based on a regenerative design process that works to gradually heal the land and ecosystems. The site was designed not only as an environmental reclamation project but as a community park and education area. The design incorporates 21 pond cavities, measuring approximately 32–131 feet in diameter and 3-16 feet in depth, that works to concentrate the water in the site in specific locations and allow phyto- and bioremediation to take place. These man-made wetland ponds simulate the processes that would have taken place on site before any development. Diverse habitats were recreated, and natural processes were initiated to decompose the contaminants. Seeds of mixed plant species were sown to start the vegetative colonolization, and other native species were allowed to grow wherever suitable. Through the seasons, patches of unique vegetation became established, corresponding to the individual wet or dry cavities, creating “Adaptation Palettes”. An interconnected network of paths and boardwalks were constructed to allow access and viewpoints to all areas and utilized educational signboards in key areas (Fig. 4.11).

**Fig. 4.11.** Images of retention cells and walkway (YouthLA, 2010)

*Design Relevance:*

This site serves as a great source for a technology demonstration or educational public park. It effectively allows access to the entire site in a safe way by utilizing raised boardwalks and bridges to separate the user from the contaminated areas.  Educational boards along the walkway explain the remediation process or qualities of specific areas, allowing the user to observe and understand them (Fig. 4.12).  Another interesting design aspect is the use of individual cavities or retention cells that concentrate the contaminants in a specific area which treats them hydrophytically.  Design-wise, the organic lines and cells are interesting and draw a direct connection to organic and biological shapes and systems.

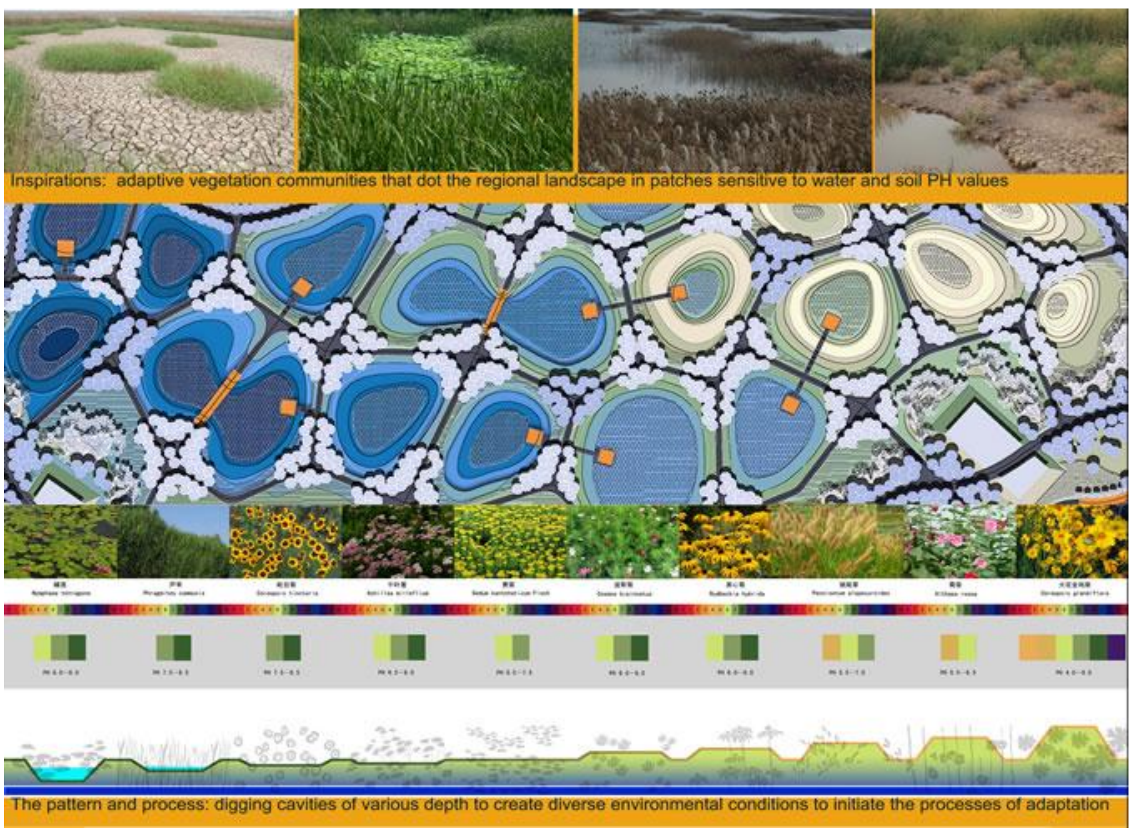

**Fig. 4.12.** Pattern of activities and environmental conditions (YouthLA, 2010)

### Case Study 4: Sustainable Schiebroek-Zuid: Rotterdam, Netherlands

This project is not a remediation project in the traditional sense. It focuses on redeveloping a residential area to improve the economic, environmental, and social conditions of the site and community living there, while not disrupting them in the process (Fig. 4.13). This project looks to the future at how to create a sustainable community.

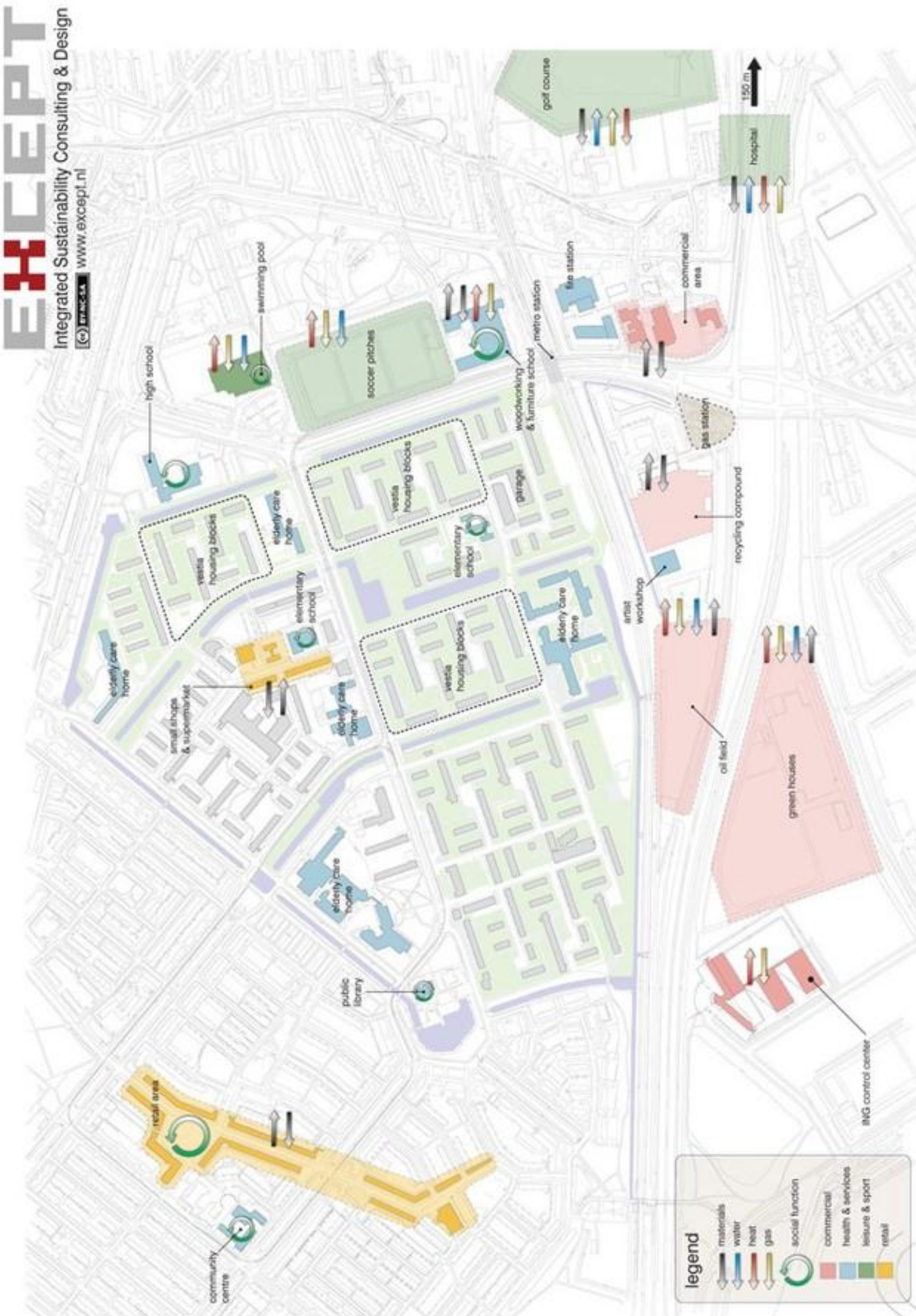


**Fig. 4.13.** Master site plan in immediate context (Except, 2010)

*The Site:*

Schiebroek-Zuid in Rotterdam, Netherlands is currently undergoing redevelopment by *Except Consulting* and *Vestia*. The site is a post-war social housing area that suffers from economic and social depression. Few people use the public spaces provided and the buildings are uninspiring (Fig. 4.14). The remediation project began in 2010 and is still in the design phase.

**Fig. 4.14.** Existing site conditions (Except, 2010)

*Design Process:*

The design utilizes a multitude of elements or “ingredients” specifically chosen for existing site conditions. It focuses on creating a sustainable community setting for many types of people that provides social services, energy autonomy, stimulating community interrelations, and fully integrating food production using edible landscaping.

The design process began with charrettes conducted by the design group with the current residents of the project site. The information and sketches created by the community (depicting what they wanted and needed) were incorporated into the design concepts and program and allowed the design group to select the appropriate "ingredients" to apply. (Fig. 4.15)

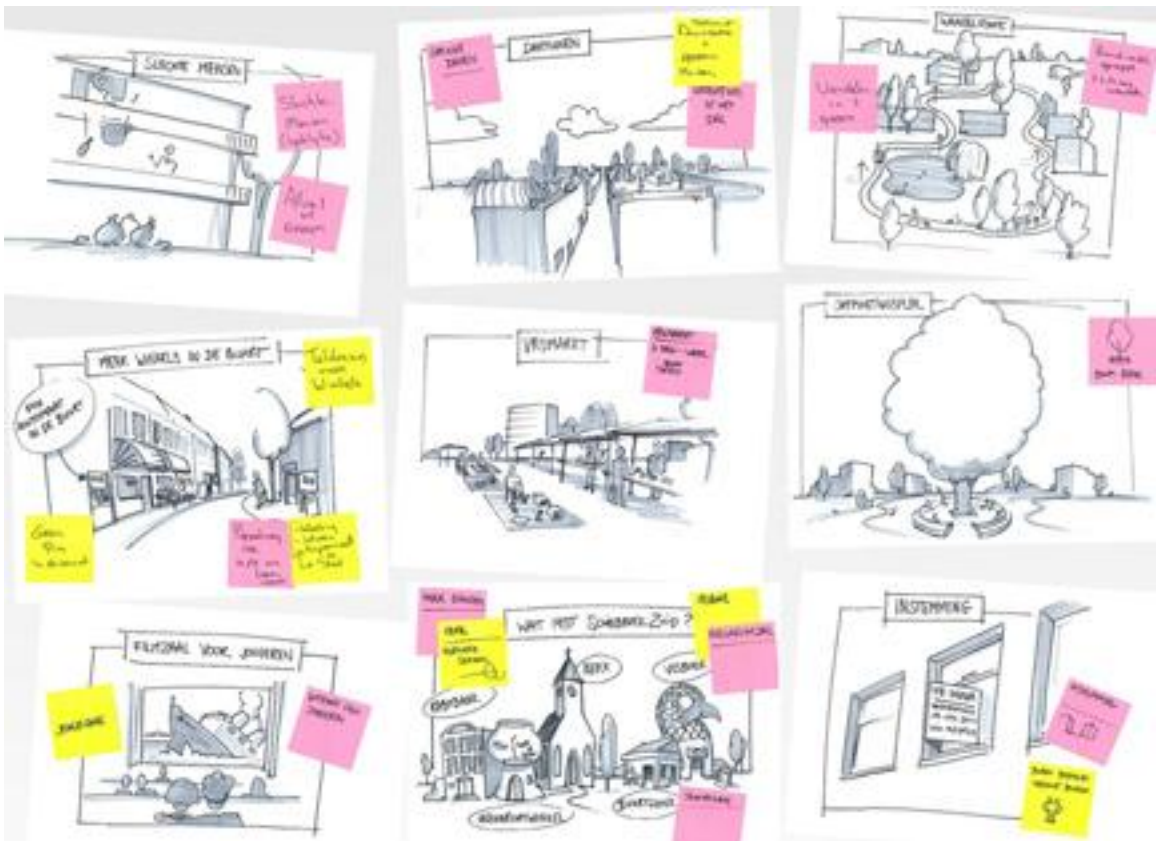

**Fig. 4.15.** Charrette sketches by community members as redrawn by design team (Except, 2010)

Using the "Symbiosis in Design Sustainable Methodology" (Fig. 4.16) the company developed, they simultaneously address concerns such as society, energy, the environment, and the individual.

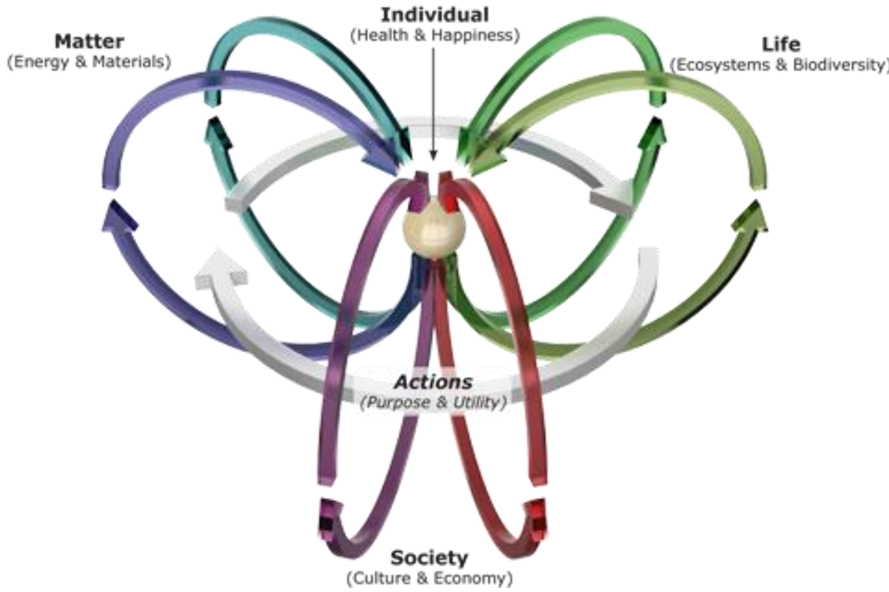


**Fig. 4.16.** "Symbiosis in Design Sustainable Methodology" (Except, 2010)

All components were incorporated into the site without causing a great deal of upheaval by retrofitting on and around the existing structures. (see Fig. 4.17)


**Fig. 4.17.** Views of urban agriculture plots (Except, 2010)

*Design Relevance:*

The design incorporates community-maintained urban agricultural plots and focuses on improving the social and economic standing of the members.  The graphics depicting this are informative and well composed.  The projected timeline (Fig. 4.18) clearly and effectively demonstrates the progress of the project and community involvement, and incorporates the history of the site at the same time.

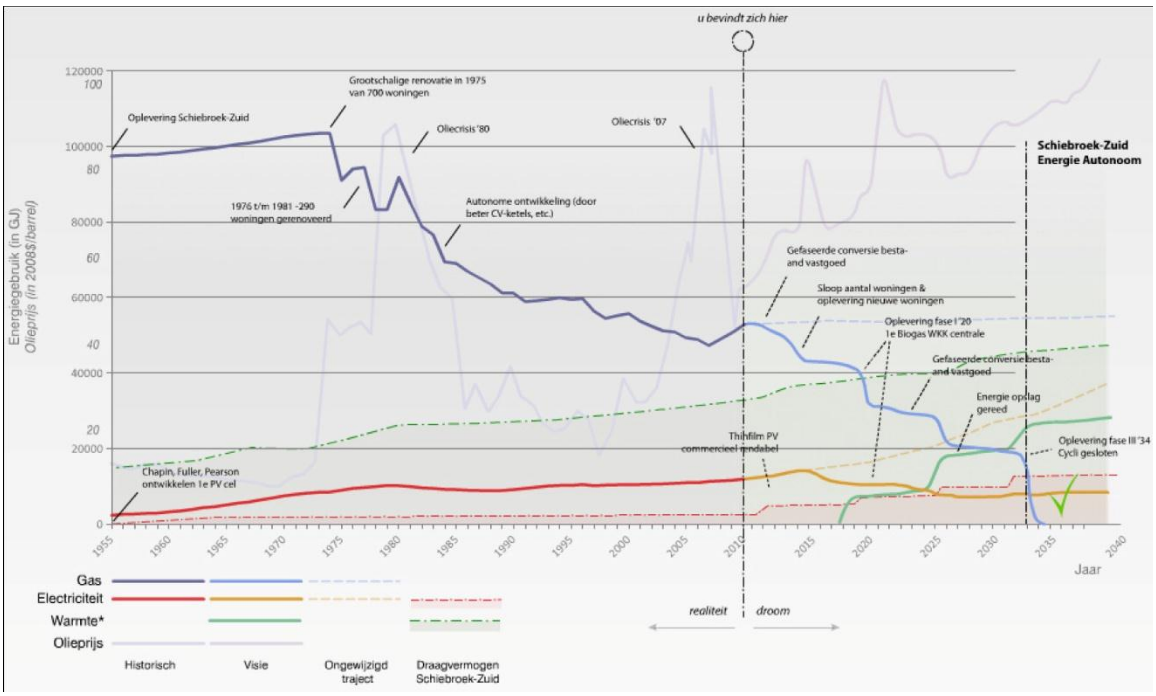

**Fig. 4.18.** Development trajectory timeline showing past and future energy needs and use (Except, 2010)

## Conclusion

The reported projects serve as useful precedent studies of designs that incorporate biological soil and water remediation and the possibilities of urban renewal for a sustainable future.  They look at the past use of the site and incorporate that to influence the site's design, successfully remediate the contaminants left by that past use, and develop the process and path for its future uses.

# CHAPTER 5 – PROGRAM, CONCEPTUALIZATION, AND DESIGN PHASES

### Opportunities and constraints:

The site inventory and analysis reveal opportunities for site design to connect different parts of the surrounding context and the presence of adjacent pedestrian pathways linking to major destinations to provide incentive for site use. Contaminant locations, historic buildings, and uses of the site can be reflected in the design and development of the site, site elements, design layout, and phasing.

Design constraints include the presence of the contaminants on site, some of the surrounding infrastructure such as the railroad, and the extreme amount of overgrowth on the project site. Another constraint is that not all contaminants can be remediated with biological remediation processes. These constraints will affect the design layout, public access and circulation, and remediation process (Fig. 5.1).

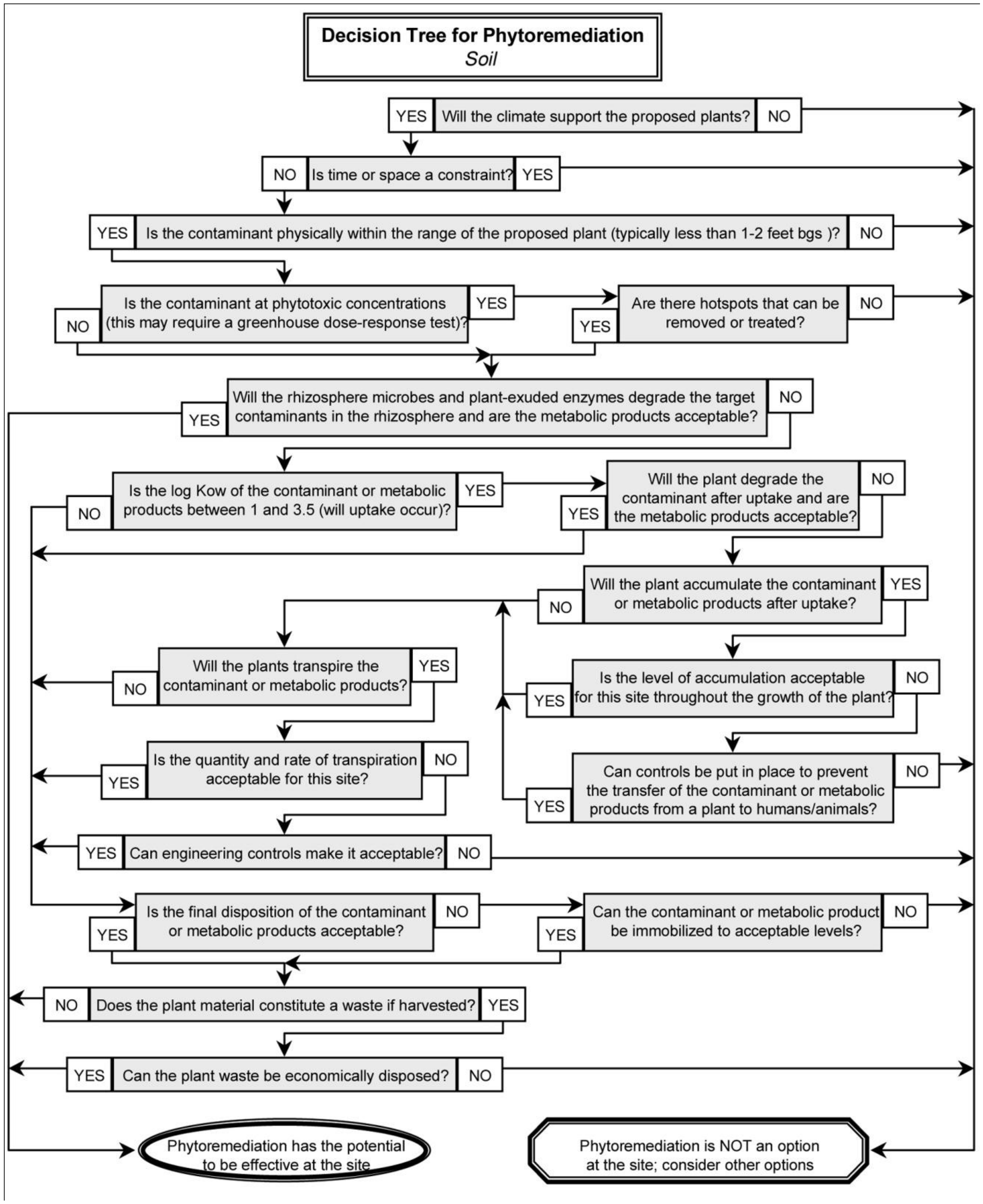


**Fig. 5.1.** Thought tree for determining suitability for phytoremediation (Environmental Protection Agency, *Brownfields Technology*, 2001, pg 3)

*The design objectives include:*

1. All soil and water contamination will be isolated from the surrounding properties to prevent its spread.
2. The soil and water contamination on-site will be remediated primarily using proven biological remediation processes.
3. The site will be developed into a public park and local urban agriculture.
4. Public access to the site and in specific remediation areas will be determined according to the type and levels of soil contamination in relation to potential human safety risk.
5. Community interaction will be programmed according to safety standards and the project will encourage public interest and interaction with the site, as an educational resource, in development of the community garden, use of a proposed trailway, and in long-term maintenance of the site in the remediation process (Fig. 5.2).
6. Remediation design and process will be led by the design team, with assistance from the community, carefully controlled to prevent possible exposure.
7. Materials harvested from the site will stay on-site and be reincorporated (except for phytoextractors destined for recycling).
8. The site will connect with the Cardinal greenway, Trailhead Park, the White River, and McCulloch Park, while also addressing safety risks such as the proximity of the railway and McCulloch Blvd.

*The program includes:*

1. Poplar tree buffer around entire site and separating high contamination areas, spaced eight feet apart in a staggered triangle pattern, four rows deep, with trees of two sizes.
2. Entry area with small classroom/meeting building, bike racks, public restrooms, and educational kiosk.
3. Retention ponds in entry area using hydrophytic remediator plant species.
4. Mesh fencing in phytoextraction areas following grid pattern.
5. Three access points on north, east, and west sides.
6. Mulch pathways made from recycled materials during site preparation and waste from poplar tree harvest/boardwalk manufacturing.
7. Raised boardwalk around retention ponds and area with highest chromium levels.
8. Educational signage and lighting in key areas.
9. Final phase installation of successional forest trees and demonstration prairie.
10. Agricultural plots sufficient for small neighborhood with area for potential expansion.
11. Tool shed and composting area for agricultural waste.
12. Demonstration beds for remediation plants

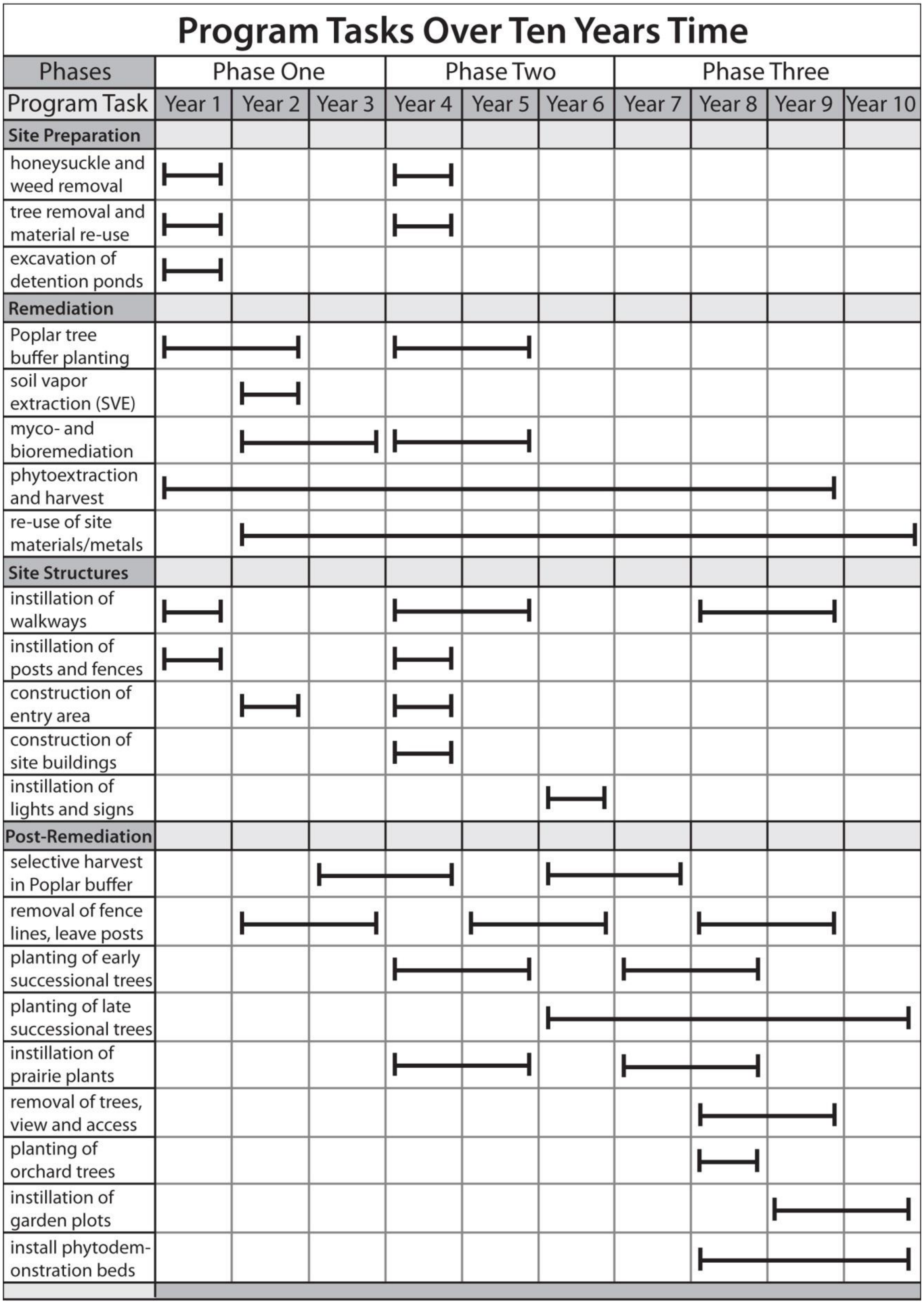


**Table 5.2.** Program tasks in a ten year timeline

## Conceptualization:

*Preliminary Concept Development:*

Initial site concepts are illustrated in Fig. 5.3. The first concept uses alternating mass plantings within the buffers. The second concept uses radiating lines from potential entry areas to create smaller, more manageable remediation areas. Dividing the site into smaller areas for the phytoextraction plants became important for the concept since this made testing and plant palette mixing easier. The third site layout uses the old foundry and auto repair shop to create and orient a grid pattern for the planting masses.

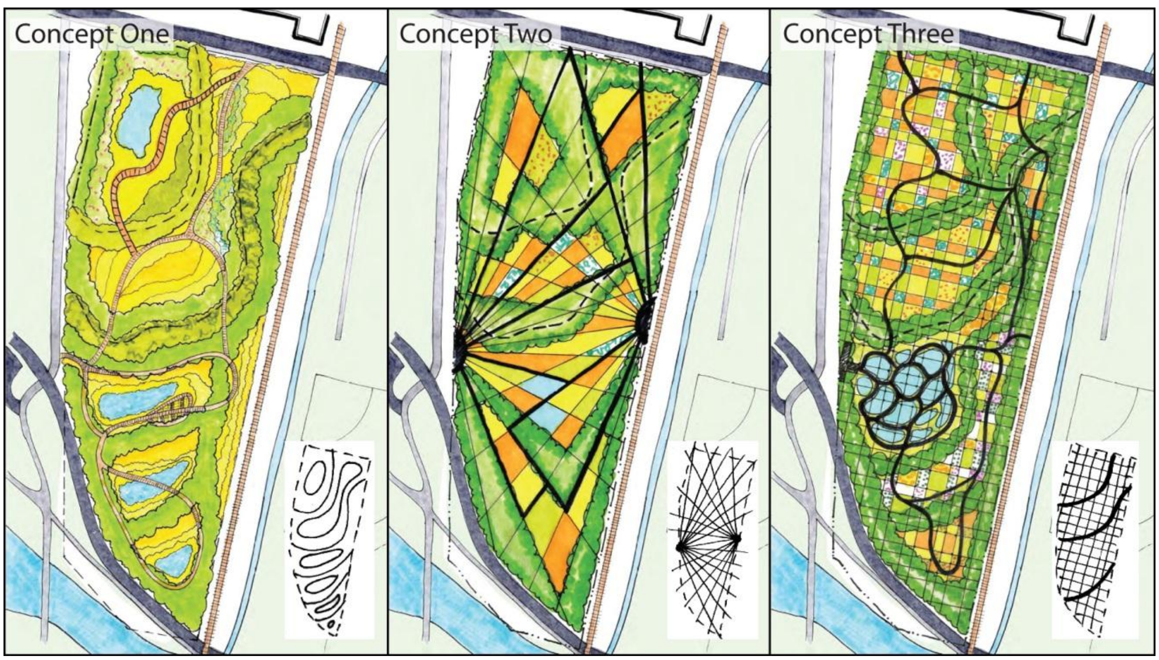


**Fig. 5.3.** Early concepts for site layout and planting plan

The main focus of the project is to remediate the site. Early concepts centered around developing a plan that uses a tree buffer to isolate the site, organic design forms, and mass plantings of hyperextractors. The buffer also functions to separate parts of the site that have higher contamination levels from those with lower levels, using varying root depths to filter and absorb contaminants in groundwater (Fig. 5.4). The concepts for the remainder of the site layout are flexible. The areas that remain the same in all concepts are the main entry area located off the Cardinal Greenway and Trailhead Park, the area determined for the community gardens in the north part of the site, and the extended remediation process in the areas contaminated with methylene chloride and naphthalene.

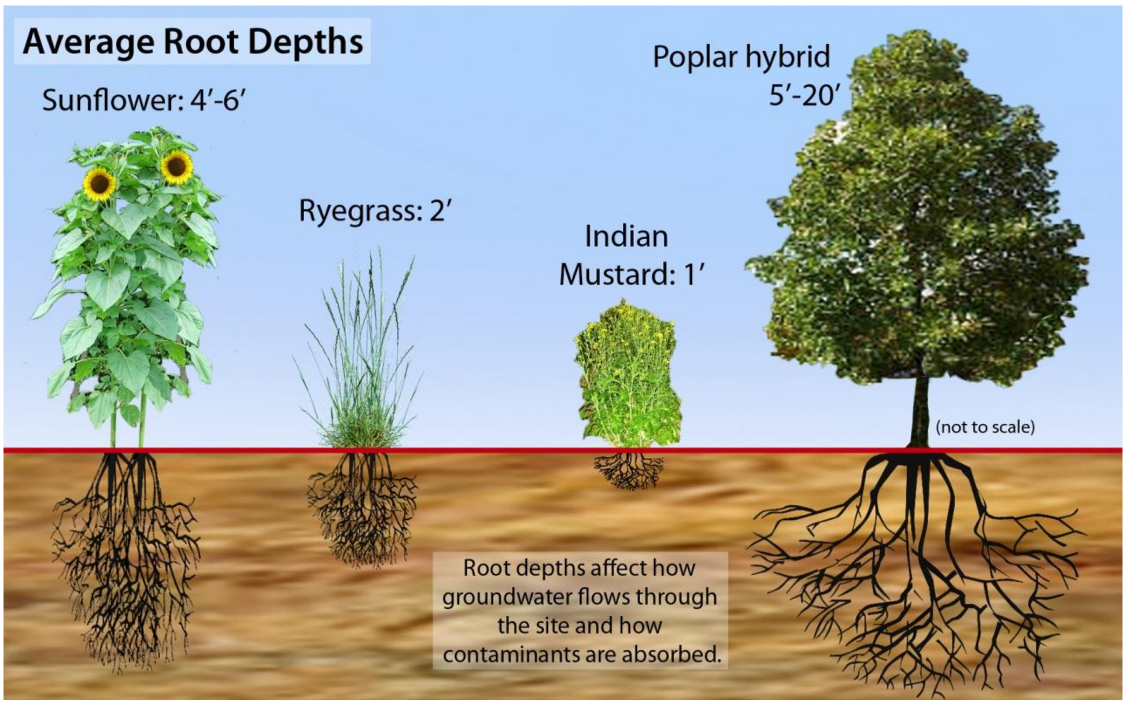


**Fig. 5.4.** Root depths applicable for soil and groundwater contamination buffers

*Remediation and Plant Choices:*

The hyperextractors chosen for the site remediation were researched for effectiveness in remediating the four specific metals found on-site. Varieties of plants used for phytoremediation are sunflower (*Helianthus annuus*), alpine pennycress (*Thlaspi caerulescens*), indian mustard (*Brassica juncea*), highland bent grass (*Agrostis castellana*), rapeseed (*Brassica napus*), smooth water hyssop (*Bacopa monnieri*), giant duckweed (*Spirodela polyrhiza*), water hyacinth (*Eichhornia crassipe*), hybrid poplars, seapink thrift (*Armeria phytorem*), blue sheep fescue(*Festuca ovina*), alfalfa (*Medicago sativa*), brassicas; bladder campion (*Silene vulgaris*), rose clover(*Trifolium hirtum*), prickleyburr (*Datura innoxia*), and tall meadow fescue (*Festuca arundinaceae*) (Fig. 5.5).


**Fig. 5.5.** Images of plants associated with each heavy metal contaminant

These plants are rotated every growing season based on their properties and proximity to other grid cells of the same variety, and will extract the metals which will then be recycled and re-used in industry.

Bioremediation and mycoremediation will be used to decompose the naphthalene and 2-methylnaphthalene in the north part of the site. Bioremediation would involve encouraging the growth (or seeding if needed) the affected area with the bacteria strain, collecting the mulch generated from site materials and seeding it with the mushroom spawn (Fig. 5.5). A shade cover such as a variety of *Brassica* or grasses can be seeded on top, of that to stop the soil and fungi from becoming overheated or dried out which would prevent or slow its growth. The mulch cover will also protect the soil and prevent the aromatic hydrocarbons from evaporating.


**Fig. 5.6.** Bioremediation *Psudomonas* spp. and mycoremediation oysters (*Pleurotus*)

A soil vapor extraction (SVE) system will be used to extract the VOCs from the affected area of the site in the northeast corner (Fig. 5.7). This is a mechanical/chemical process that must occur before the site is ready for biological remediation as it forces heated air into the ground which will kill off most plants. The area is small, which will minimize costs and the spread of this negative effect.

### Final Concept Development:

The third early concept was used as a launching point for the final concept and design. The contamination levels diagrams were layered together to show overall heavy metals and other types of contaminant concentrations (Fig. 5.7) and then used as a basic template for the poplar buffers, mycoremediation and SVE areas, and expected phase completion. This, combined with the grid pattern created in the previous concept, defines the overall planting pattern (Fig. 5.8).

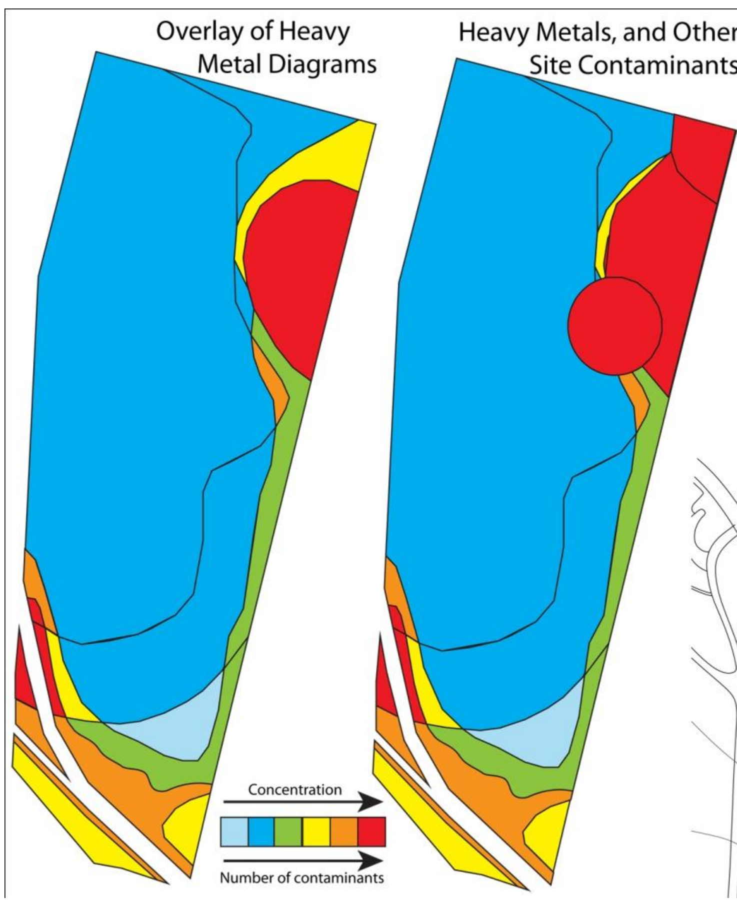


**Fig.5.7.** Combined contamination levels

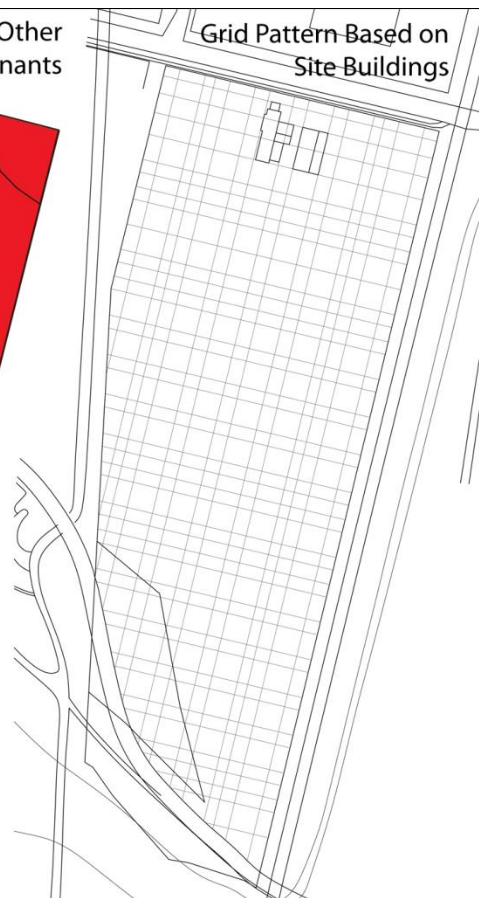


**Fig.5.8.** Grid pattern overlay

The metal remediation program uses the grid to divide the space into more manageable sizes and to organize plant types, but the larger areas with the other types of contaminants are separated into three large masses separated by buffers. The grid will be used when an area is ready for phytoextraction.  The grid when installed in these areas, will be made from posts and fence lines creating physical barriers limiting public access to the contaminated areas, and the posts will remain indefinitely as visual reminders of the process.

The site access and circulation depends on the levels of contamination, with the lowest-level areas opened to public use first.  The main access off the Greenway and Trailhead Park provides the greatest possibility of site interaction in its earliest phases.  A gateway experience is created by a platform and demonstration plantings framing the entry.  Retention ponds surrounded by raised boardwalks are also located nearby, providing another draw for potential users.  An access point from the north is included in the second phase as that area is opened up for remediation, and a looping trail system extends from the main entry through that area.  After the third phase is completed, a third access is developed at a point opposite the main entry, opening the site to access from McCulloch Park.  A safe crossing area is created across the tracks and drainage channel (Fig. 5.9).


**Fig. 5.9** Phase development over time

The walkway will extend as a raised boardwalk through the phytoextraction area that was once contaminated with hydrocarbons and VOCs to prevent contact with the soil. This boardwalk will also be installed around the retention ponds, and the rest of the walkway will consist of wood mulch. Visual access points are installed during this phase that look into the site from the Cardinal Greenway and McCulloch Blvd.; however, these will not encourage pedestrian access. Ingress or egress at the south boundary of the site is made dangerous by the street conditions and low visibility. Installing a crossing area or sidewalk on the interior edge of this section of road would be difficult with the existing infrastructure and narrow road edge.

The design, when fully mature, will be a native successional forest park and prairie demonstration area in the center and southern parts of the site, including wetland demonstration ponds in the entry area; community gardens, orchards, and phytoremediation demonstration beds in the north-west part of the site.

## Design Phases:

***Phase One, Years 1-3:***

The first phase of this remediation project involves primarily site preparation and development of the southern part of the site, which contains the lowest number and concentrations of contaminants. A secondary area prepared in this phase is in the northeast that is contaminated with naphthalene and methylene chloride. A section-timeline of the growth and harvest of the poplar buffers and installation of urban agriculture plots is illustrated over the full phased remediation process (Fig. 5.10).

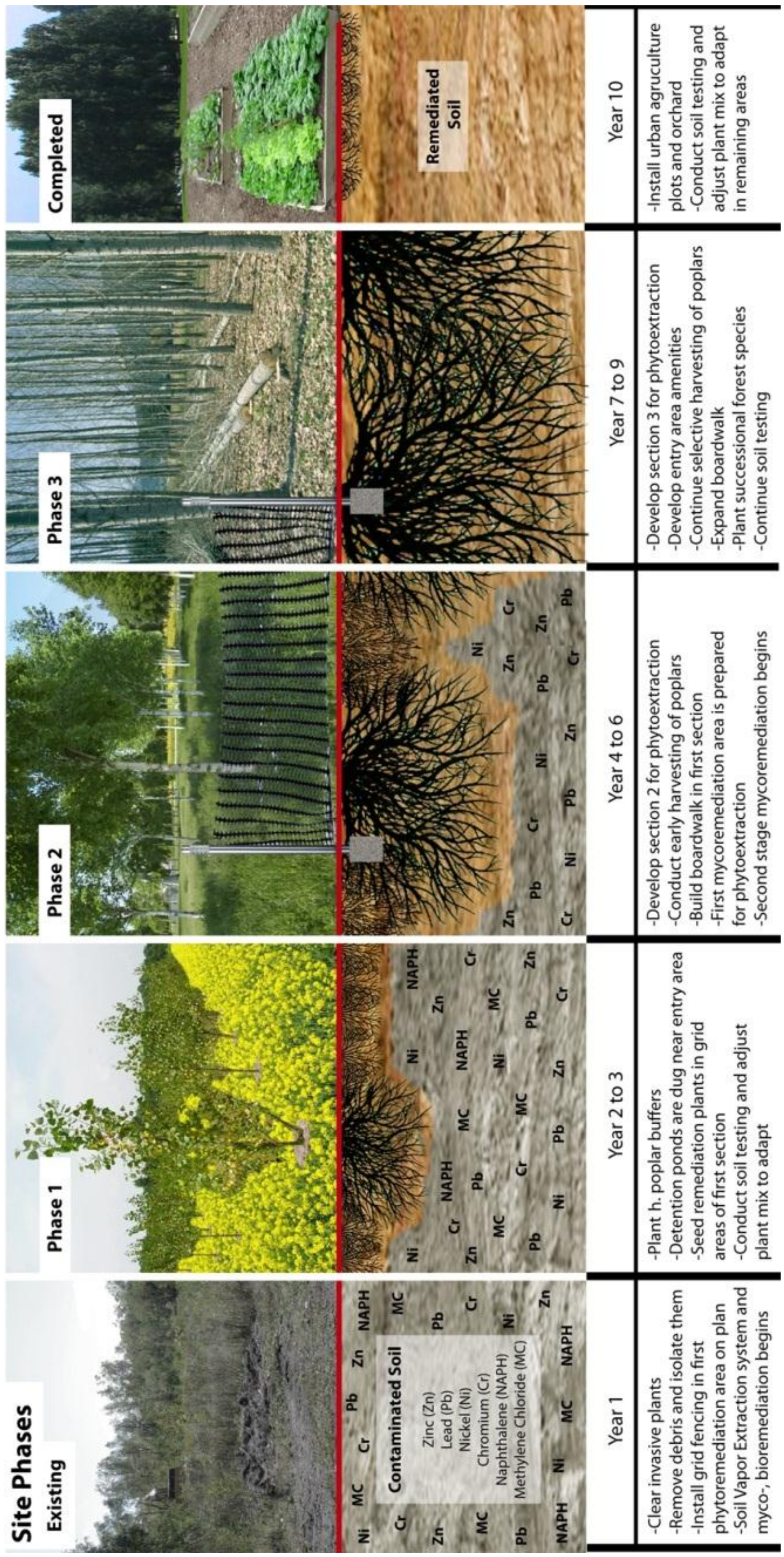


**Fig. 5.10**. Section-timeline of general phasing of the site and cycle of *Populus* buffer

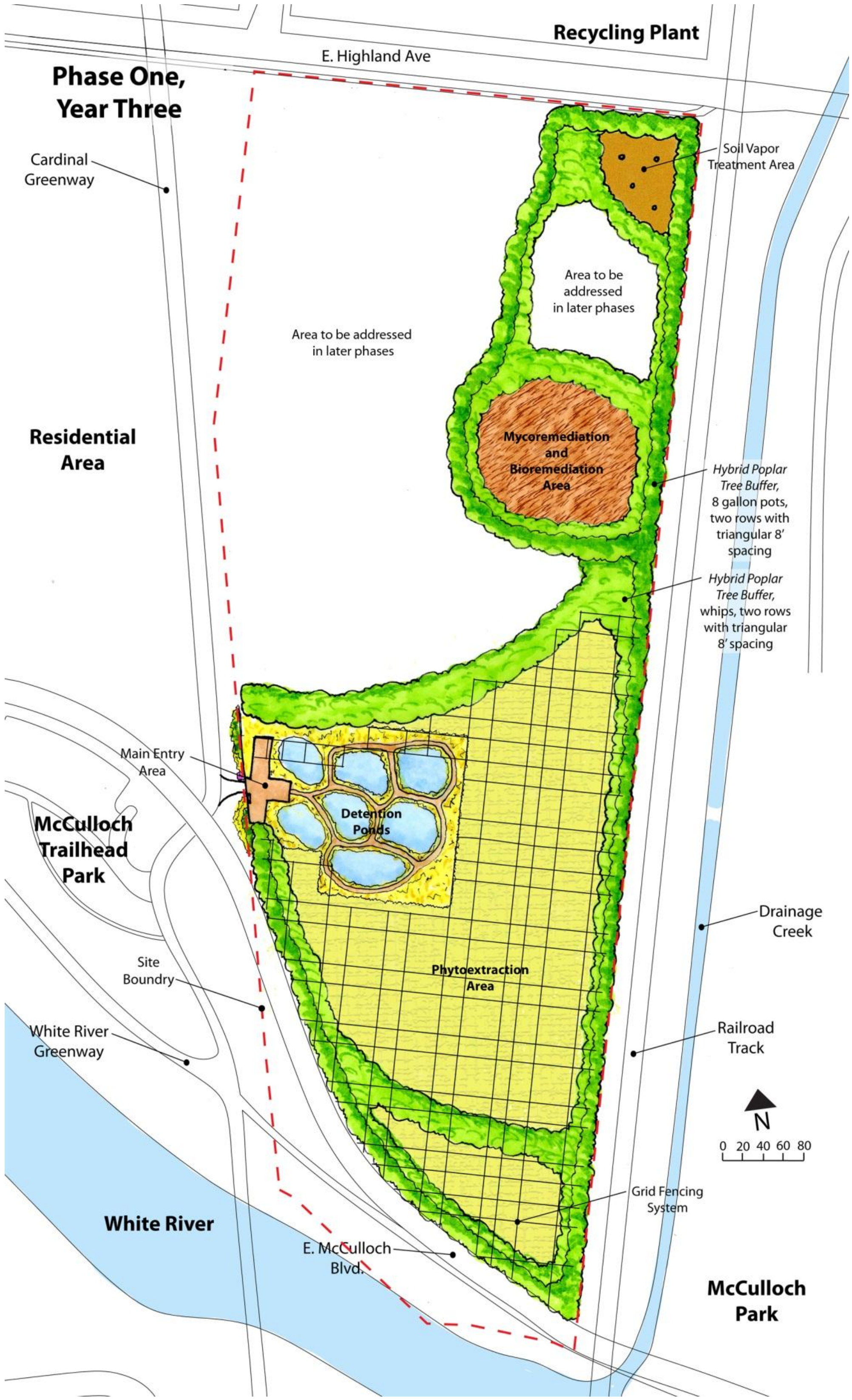


**Fig. 5.11.** Plan at end of Phase One showing completed phase plantings and design extent

*Year One:*

Year one preparation of the site will include removal by cutting of the dense bush honeysuckle (*Lonicera maackii*) growth along the edges of the site (Fig. 5.12). The biomass must be disposed of properly to prevent accidental propagation by root or berries. Perhaps the mass can be burned, (as composting does not always kill it) and the ashes tested for contamination before disposal or reincorporation into the site soil. The plant stumps will be monitored and treated to prevent them from sprouting. The denser weed growth will have to be removed in the proposed area to prepare for the planting phase.

**Fig. 5.12**. Japanese bush honeysuckle (*Lonicera maackii*) infestation and site litter

Trees that are healthy and non-invasive will be allowed to remain while others will be selectively removed. Other trees will be removed if they interfere substantially with the design. This material can then be used on-site, depending on its quality, as either wooden posts for the grid fence-lines or mulched (Fig. 5.13) and used as a walking surface, or as compost for the growth medium in the mycoremediation area.


**Fig. 5.13.** Options for harvested wood materials on site, kept and used on site

A grid is used to break up the site design into more manageable sections when dealing with the distribution of heavy metals across the site. These sections were designed following lines and orientations of the once-existing building and foundry across the street. Each section will be seeded with a particular variety of plant species chosen from the planting palette (see Fig. 5.5), based on the type and level of contaminant present in the soil. The plant choice will vary from its neighboring section, from each growing season to the next, to provide variety and visual interest (see Fig. 5.14).

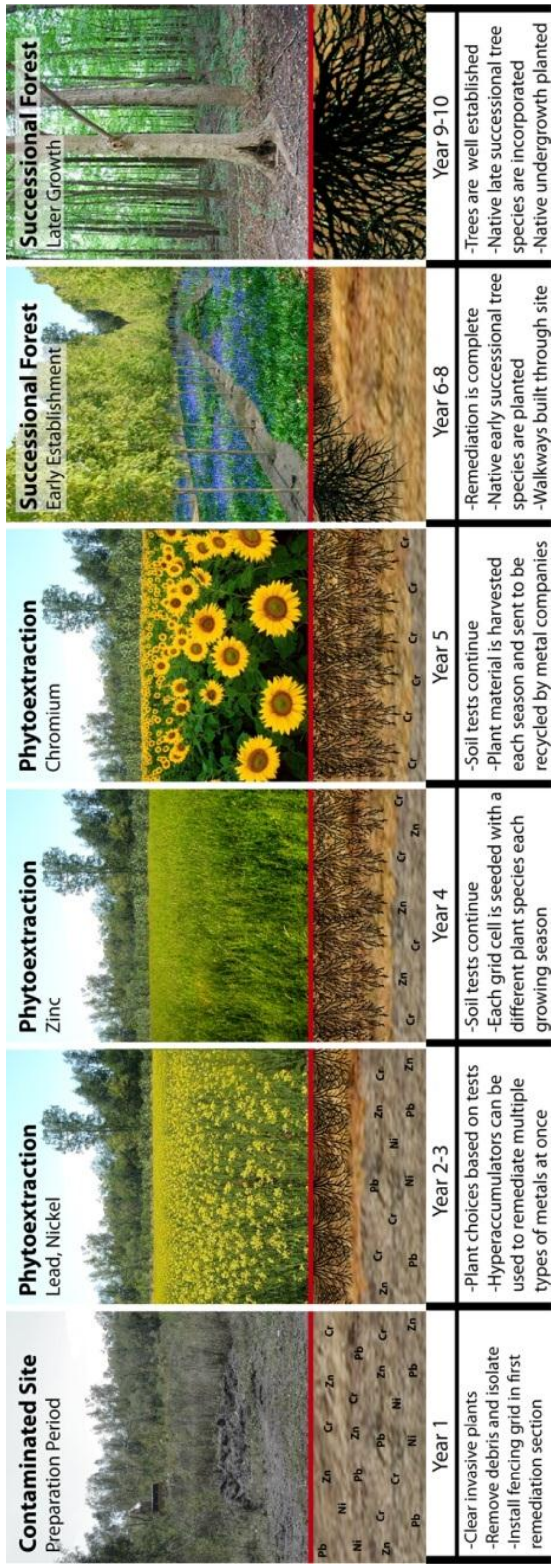


**Fig. 5.14.** Section-timeline depicting remediation in area contaminated with heavy metals

The soil and/or vegetation in each section will be tested periodically to determine the types of heavy metals and their levels of contamination, and what species of plant will be used for their extraction. Mesh fencing along the grid lines will be erected with wood posts at the intersections. The fence lines provide physical barriers and visual cue of the boundaries for individual sections or cells. These will be removed when each is fully remediated, allowing full public access to that area (Fig. 5.15).

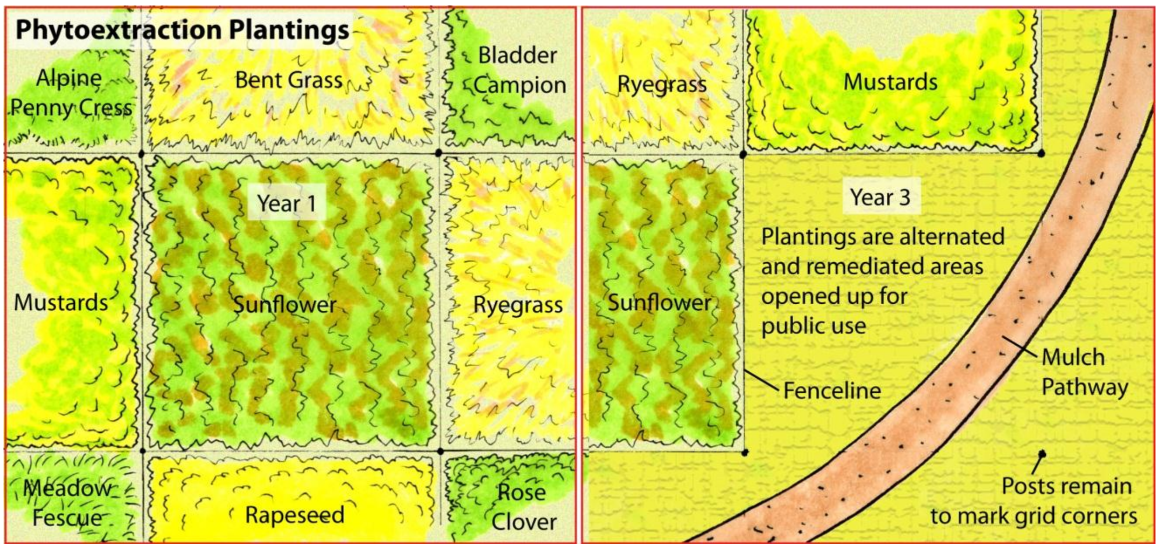


**Fig. 5.15.** Plan for phytoextraction plantings showing change and removal of fencing

Retention pond depressions will be installed in the area near the main entrance. These will be located according to the site plan and excavated to the water table level. They will be un-lined, allowing surface water to collect and groundwater to infiltrate. These retention areas will be planted with hydrophytic remediators (Fig. 5.16) that are particularly successful at removing the heavy metals. A preliminary pathway connecting the Greenway to the main entry, and then looping around these depressions, will be installed using the mulched material harvested from the site.


**Fig. 5.16.** Plants in retention area

The boundaries of the site will be planted with a fast-growing hybrid poplar species intermixed among the existing trees retained during site preparation. The areas contaminated with methylene chloride and naphthalene must be isolated from the rest of the site. The design uses the same hybrid poplar trees as a root buffer to phytostabilize the soil and to keep these contaminants from moving into or through the water table. The areas that need to be stabilized quickly will be planted with eight-gallon plants set eight feet apart following the same grid pattern. The outermost edges of the buffer away from the contaminant will be planted with whips of the same type, saving on overall cost and staggering the growth of the trees (Fig. 5.17).

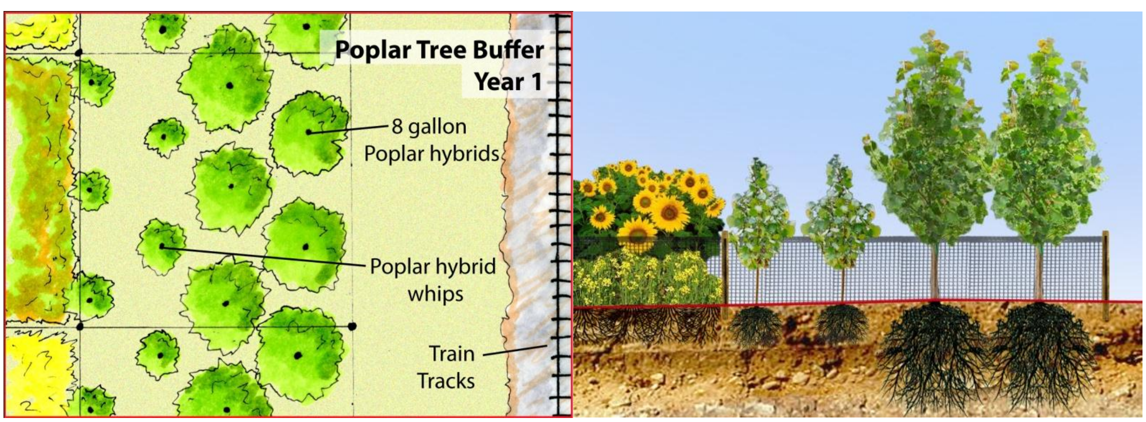


**Fig. 5.17.** Poplar tree buffer plant sizes at installation

These whips will also be used in areas where isolation is not as essential, so dominant growth is not needed immediately or in areas where development is not part of Phase One.

Growth of the hybrid poplar can range from five to nine feet per year, so the tree buffer will be established quickly.

*Year Two:*

After every growing season, the mature metal-enriched plants will be harvested, tested, and recycled according to what contaminant was extracted. These will be harvested before producing seeds to prevent unwanted spread of the plants. Different industries in the area such as *Exide Technologies*, a battery manufacturer, can take the biomass directly from the site and reduce it to ash to extract and re-use the metals. This seeding-growth-removal-recycle process will continue in each section every growing season and throughout the site until the heavy metal contamination is at or below safety standards set for urban agriculture.

The area contaminated with naphthalene and 2-methyl naphthalene within its established tree buffer will also be prepared for development in year two. This process will be gradual, as the contaminants volatize readily. The first action will be to use bio- and mycoremediation in areas of high concentration, using a layer of wood mulch from the site seeded with oyster mushrooms along with other local varieties (Fig. 5.18). The compost layer will provide a growth medium, prevent the contaminant from evaporating readily, and prevents the soil from drying out and killing the seeded fungi. There is no need to harvest or remove any of the materials used -- they are breaking down the toxic hydrocarbons into non-toxic forms. The leftover organic matter will then be incorporated into the soil before beginning the phytoextraction process.

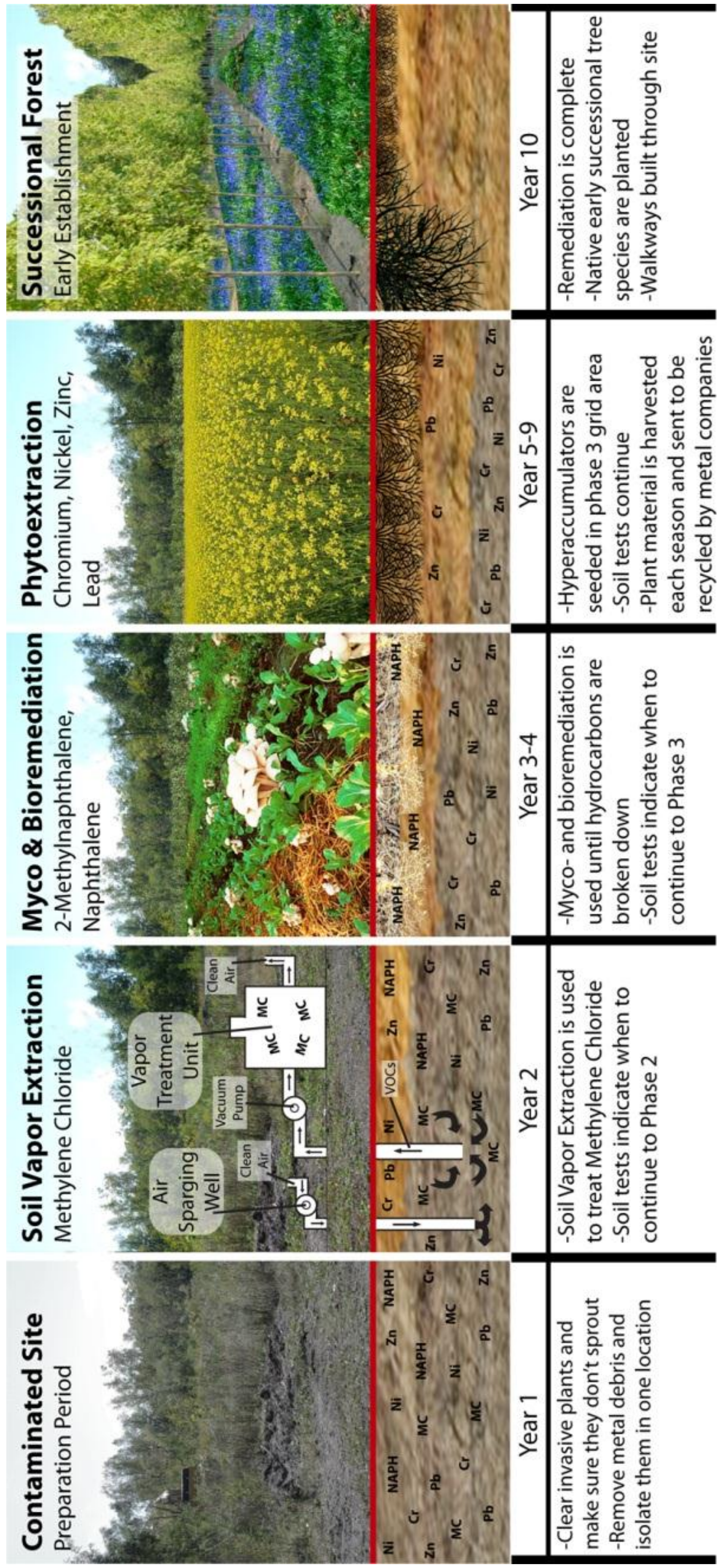


**Fig. 5.18.** Section-timeline depicting remediation of methylene chloride and naphthalene

The area contaminated with methylene chloride will use a soil vapor extraction (SVE) system for its removal (Fig. 5.18). The units will have an effective diameter of about 30 feet and shall be installed according to the site plan (Fig.5.11). Heated air is forced through pipes underground, accelerating the natural volatilization process. The resulting vapors will be collected in granulated activated carbon (GAC) canisters and disposed of after a year.

*Year Three:*

Testing of the soil and maintenance of the plants and fungi continues in year three. Adjustments to the planting scheme will depend on soil testing results, and the tree buffers will continue to mature. Observation of the SVE system will continue until soil tests show no sign of methylene chloride. Once tests are conclusive the system will be removed and the area prepared for the bio- and mycoremediation processes.


**Fig. 5.19.** Plan at end of Phase Two showing completed phase plantings and design extent

**Phase Two, Years 4-6:**

The second phase is a continuation of the processes started in Phase One, expanding the phytoremediation processes into the Phase Two area. The large open area in the north that is not contaminated with methylene chloride or naphthalene will be cleared of excess overgrowth and prepared for remediation.

*Year Four:*

The Phase Two remediation area will be prepared for development following the same process of weed and invasives removal and plant surveying as described in Phase One. The same tree buffer of mixed-age poplar hybrids used before will be planted to complete the isolation of that area.

Areas that have been tested and show natural heavy metal levels will now be planted with native successional forest trees (Fig. 5.20) or massed prairie plantings indicated on the plan (Fig. 5.19). This will continue each growing season as grid sections are tested and opened up for use.

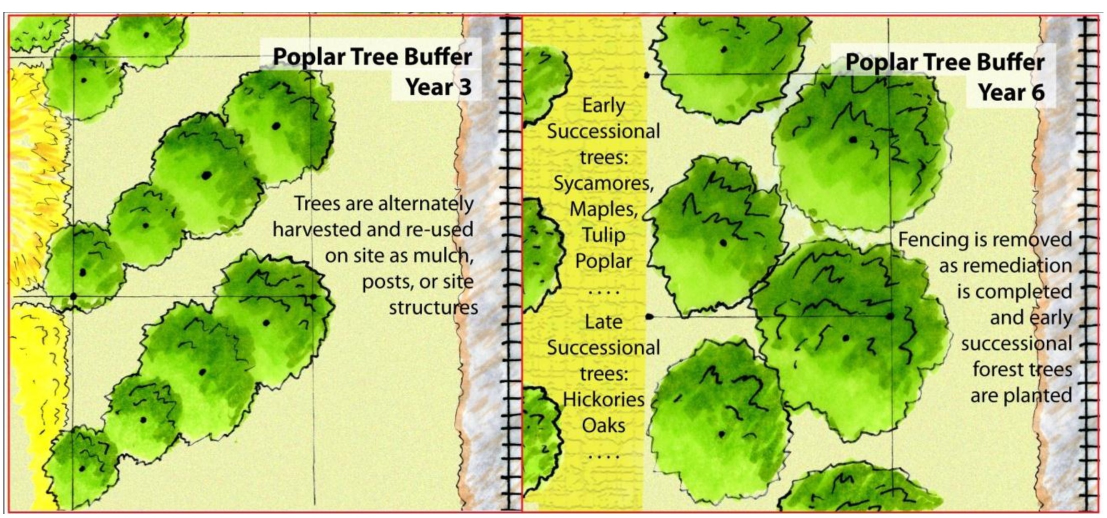


**Fig. 5.20.** Growth and harvesting of trees in buffer area

The area containing high levels of aromatic hydrocarbons which underwent remediation is now ready for heavy metal extraction.  Plantings chosen according to the process used in Phase One will be installed or seeded depending on the species.  The secondary area with aromatic hydrocarbons and methylene chloride, will now be prepared for bio- and mycoremediation as indicated on the Phase Two master plan.

*Year Five:*

The new tree buffer planted along the north-west perimeter of the site in the Phase Two master plan (Fig. 5.19) will be planted. Fence lines will be installed according to the site plan and each section seeded or planted according to contamination levels.  Heavy metal remediation processes in this area will follow those used in Phase One.

A raised boardwalk (Fig. 5.21) will be constructed from mature poplar trees harvested from the buffer area.  These trees need to be thinned to encourage healthy growth, and the materials should remain on-site.  This boardwalk is a temporary structure used in areas where people should not have contact with the soil or water.  It will provide a safe way for the public to navigate the site in areas that are still contaminated, and provide a pre-determined path for them to follow without causing a disturbance to the plants or soil.  Pathways will be extended from the existing pathway to other areas in the site; they will use the waste wood material generated during the boardwalk construction, similar to the mulch material used in Phase One.

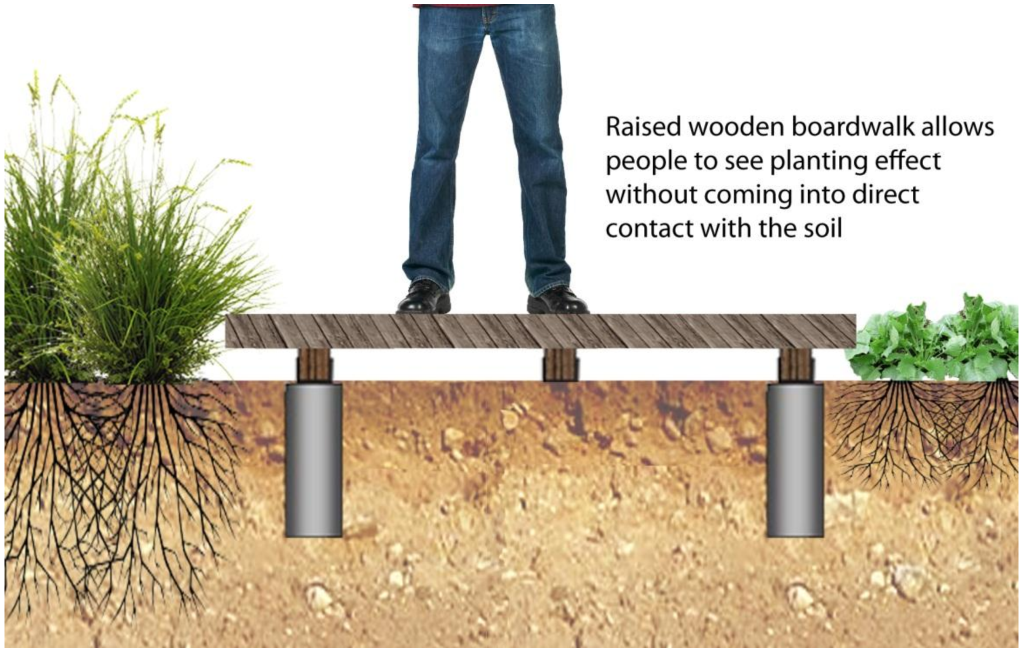

**Fig. 5.21.** Section of raised boardwalk

*Year Six:*

The areas under bio- and mycoremediation will now be planted/seeded for phytoextraction. Walkways will be extended through this area as well, allowing safe public access for observation. The phytoextraction process and poplar harvesting will continue in buffer areas. Treated areas will be planted with appropriate species or varieties indicated on the Phase Two master plan (Fig. 5.19).

The main entry area will be developed further, incorporating amenities such as bike racks, educational/interpretive signage, and a small building with a class/workroom and public restrooms constructed of harvested or recycled materials (Fig. 5.22).

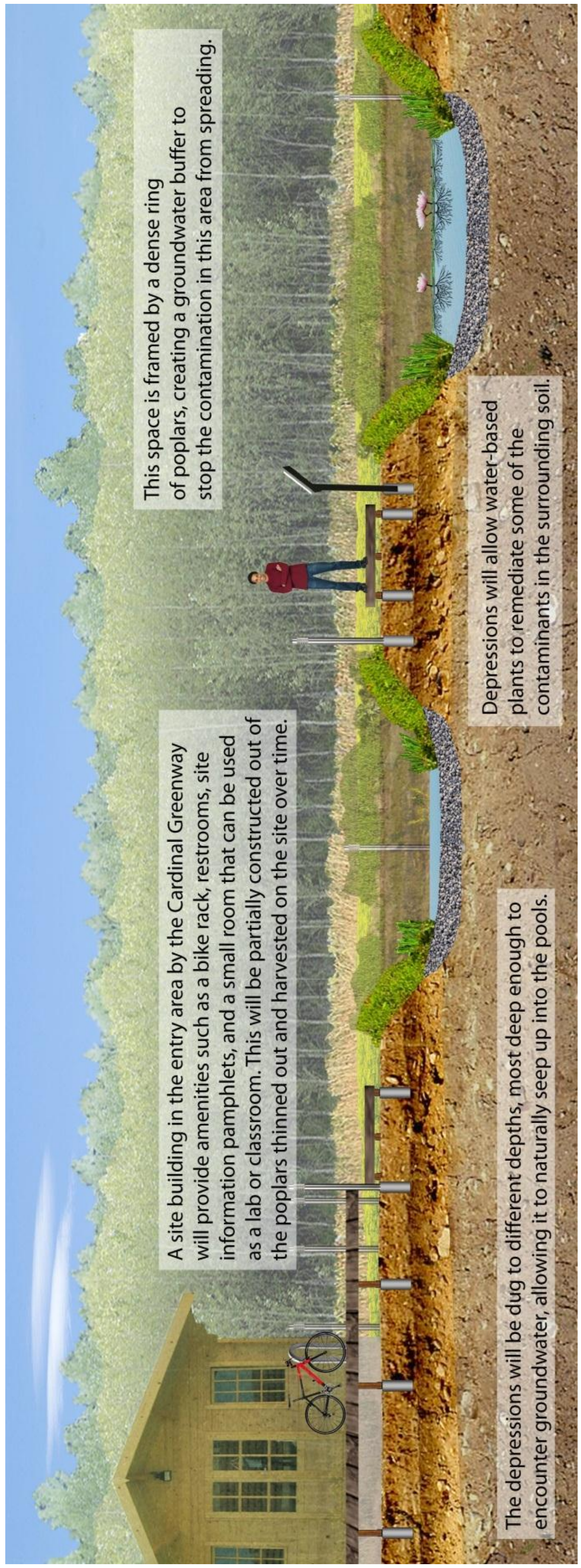


**Fig. 5.22.** Section of main entry and retention ponds

Stainless steel fence lights will replace wood posts along the pathway, and will reflect the foundries' former presence (Fig. 5.23). These will provide lighting for the walkway and can be programmed to illuminate specific sections referenced on the signage (Fig. 5.24). Trails will extend through poplar buffers to connect the main entry boardwalk to the newly developed areas (Fig. 5.25).

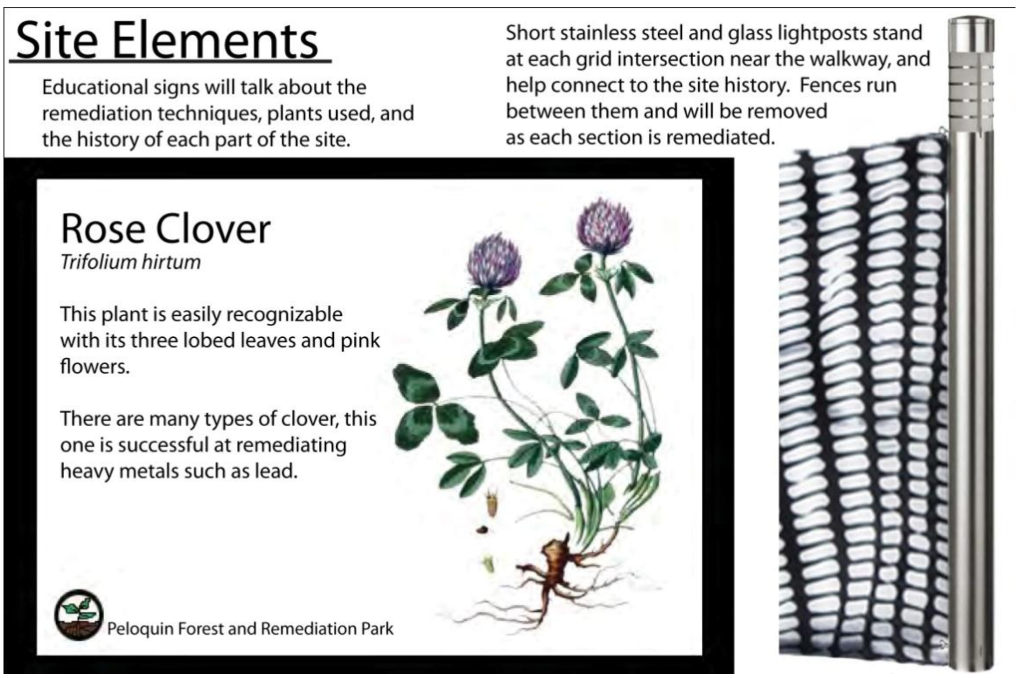

**Fig. 5.23.** Signage for walkway and stainless steel fence light posts

**Fig. 5.24.** Winter scene depicting site use and fall of colored lights on the snow

**Fig. 5.25.** Walkway through established poplar forest buffer area


**Fig. 5.26.** Plan at end of year nine in Phase Three showing completed native plantings

***Phase Three, Years 7-10:***

This phase concludes the remediation process and focuses on developing the site fully into a public park and community garden (Fig. 5.26). The trail system is complete and open for use, and provides new opportunities for visual access within and beyond the site (Fig. 5.27-28).

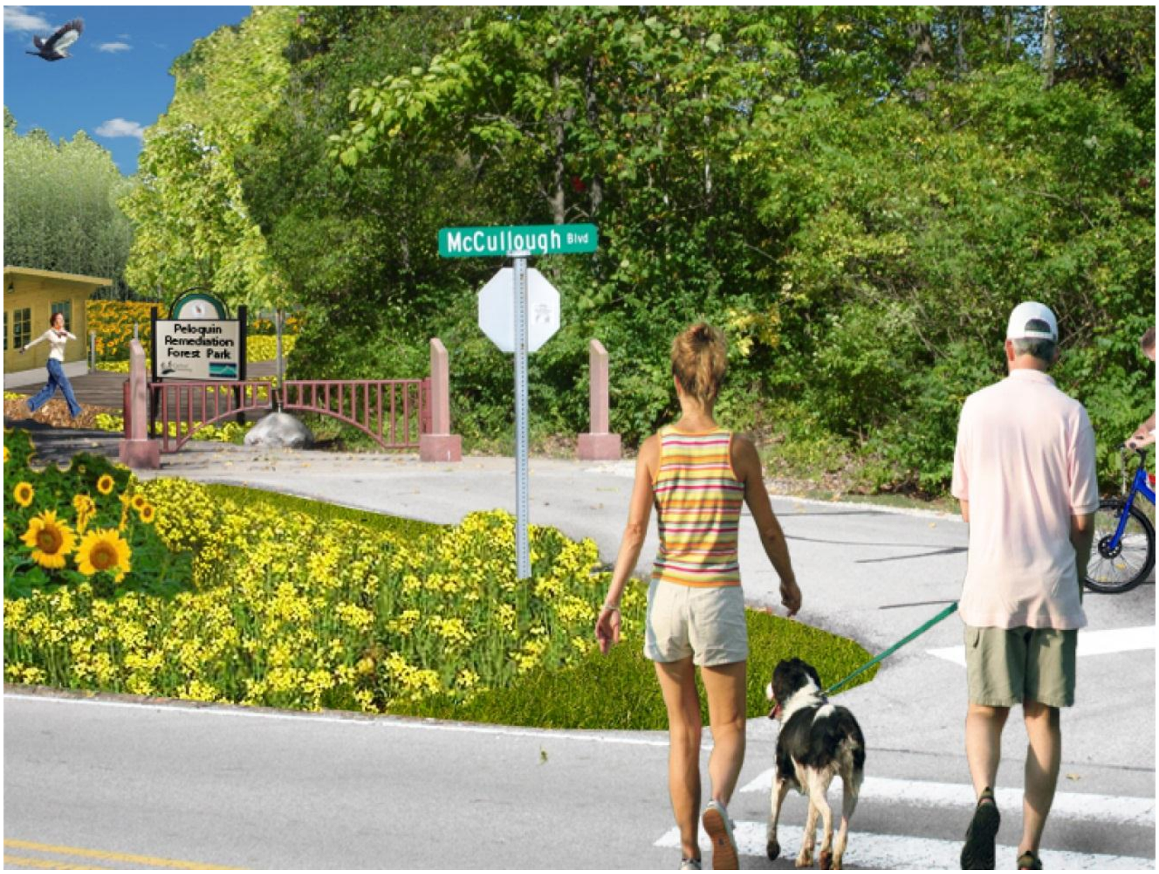

**Fig. 5.27.** Crossing McCulloch Blvd. and up the Cardinal Greenway to the site entrance

**Fig. 5.28.** View into site from main entry area

*Year Seven:*

The remediation process will continue until phytoextraction areas in the north-west are fully remediated. Additionally, the successional forest area is expanded and secondary plants are installed.

*Year Eight:*

Secondary access points are developed in the north and east as shown on the Phase Three master plan (Fig. 5.26), and views into the site are opened up at key points allowing glimpses into and out the site. Remediation continues in areas of highest concentrations. The boardwalk, signage, and lighting will continue to extend along the pathways throughout the site.

*Year Nine:*

Remediation will continue in areas where contaminants are still above acceptable levels, but at this time most of the site will be remediated. The community garden area will be developed at this point with an emphasis on plant cohabitation. The perimeter will be lightly fenced to prevent animal infestation.

*Year Ten:*

The community garden will continue to be developed. Demonstration areas for native plant groups and the different remediation types will be developed and described with signage on the walkway. The site is now complete and open for full public access.

## Conclusion

The phasing of this project is dependent on many factors, including soil testing, which can change the length of the project. This timeline is an estimate that allows for a certain amount of error, and errs on the conservative side for the amount of time needed for remediation of the contaminants on-site.

# CHAPTER 6 – CONCLUSION AND FUTURE DEVELOPMENTS

## Cost estimate:

Cost estimate comparisons are an effective way to indicate the value of a natural system as compared to the use of alternate technologies. This can be difficult to determine as the scope of the project is not determined as a final product, but a system spreading further than just the boundaries of the site. It not only deals with remediation, but also the long-term changes made to the community and the environmental systems around it. A cost estimate is proposed, but the scope at this point in time, limits conclusiveness. It will be assumed that this project would show the same results as other projects using phytoremediation on similar contaminants (Appendix A, Fig. 6.1. Table 6.1, pg. 130, through 6.5, pg. 133).

A cost assessment will be made based primarily on the cost of remediation and aesthetic/environmental qualities, when using biological methods in comparison to other mechanical methods. The estimate will consider the initial costs for the poplar trees needed for the site and the plant seed for the entire phytoextraction area. This assessment is also taking into account the visual benefits of using a plant system instead of, say a clay cap across the entire site, which would be more cost effective but would have no positive effects on the community other than isolating the contaminants.

An estimated cost will be determined for the mycoremediation process based on completed projects and the area treated on-site. This estimate would not include the organic growth medium, as the proposal uses material harvested from site. Bioremediation costs would be limited to the purchase of bacterial colonies if it becomes necessary to supplement existing soil colonies.

This proposed estimate will not take into account the costs of the design elements that are not essential to the remediation process. Materials harvested on-site are expected to save money, such as the wooden posts obtained from the initial site preparation and poplar thinning process, as opposed to purchasing the materials elsewhere.

**Future Design Use:**

Possibilities exist for this project to be used as a starting point for other sites within the city or the region. This site would help to connect the series of parks and greenspaces along the White river, and provides an alternative type of park to those currently existing in Muncie. The design layout was purposefully made flexible enough to accommodate any changes in site conditions. The phasing process and incorporation of the community are important parts to the project and can be used as a template in other situations.

If this project is implemented, public interaction and community involvement would be carefully considered for safety reasons. There are many things community members can do with little or no risk involved. In the long-run local citizens are the ones needing to get involved so they will support this kind of project, making it acceptable to other communities. The public can use the site for recreation in approved areas and it will create a stopping and crossing point for people using the Greenway or crossing into McCulloch Park. Community work can include long-term maintenance, with proper precautions during remediation, and when the site is a completed park. The community-managed garden, when installed, will create substantial involvement, increasing the sense of pride and ownership. Other work can involve informing others about the site which encourages use and spread of awareness and remediation efforts.

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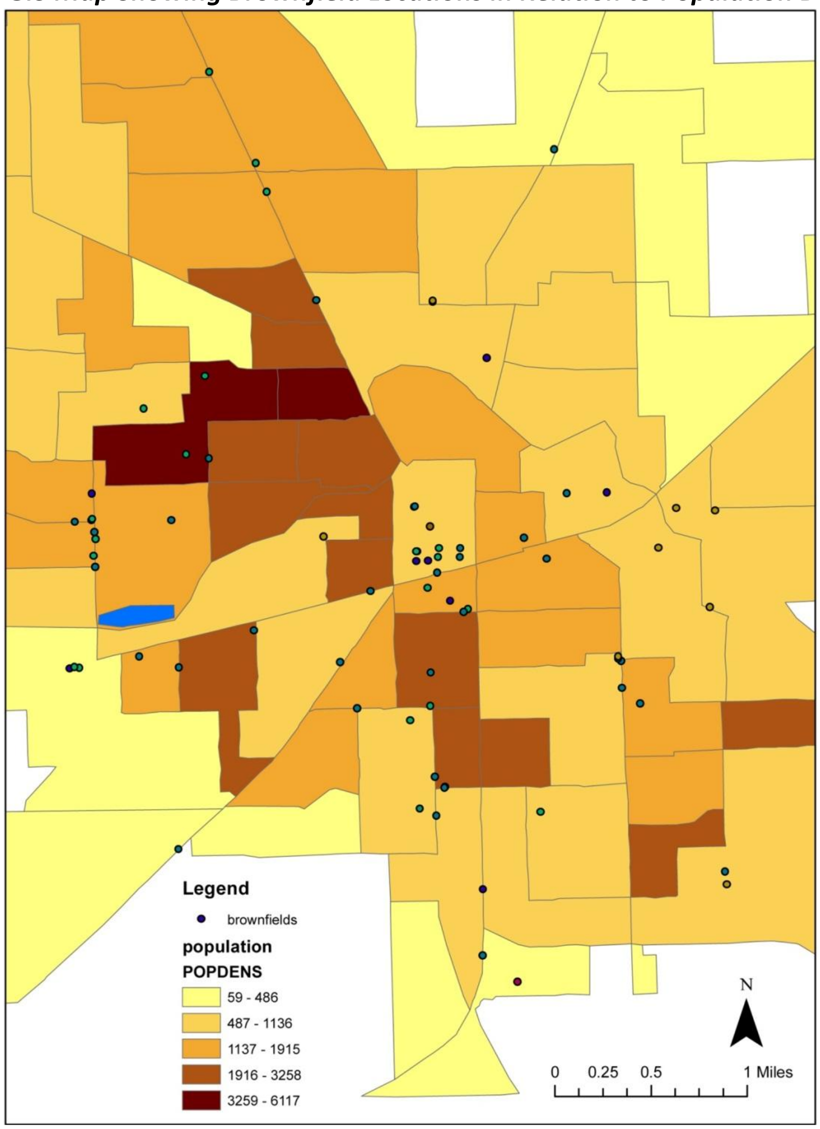
# APPENDIX A

*Fig 1.1. GIS Map Showing Brownfield Locations in Relation to Population Density*




**City of Muncie, Indiana**

## *Fig 1.2. Common Misconceptions About Brownfields*

| ***MYTH*** | ***FACT*** |
|---|---|
| Brownfields are all large, former industrial or manufacturing sites. | While some brownfields are large former industrial sites, the majority of the estimated 500,000 to 1 million brownfields in the United States are small properties like dry cleaners,vacant lots, or gas stations. |
| A site must actually be contaminated to be considered a brownfield. | The perception that a property may be contaminated can be just as great a barrier to redevelopment as actual contamination. Therefore, sites where contamination is merely perceived, and site conditions are unknown, are still considered brownfields. One third of the brownfield sites that have been assessed with EPA brownfields funding have turned out to be free from significant contamination. |
| Superfund sites are brownfields, or brownfields are Superfund sites. | Under the statutory definition, brownfields do not include Superfund sites on the National Priorities List (NPL). A small number of Superfund sites, approximately 1,200, have been designated NPL sites and are managed under a more elaborate process than most brownfield sites. |
| Brownfields are only an urban problem. | Contaminated properties affect nearly every town, large and small. Small and rural communities are impacted not only by former industrial sites, but by closed gas stations, dry cleaners, old dumps, contaminated rail yards, mine-scarred lands, agricultural wastes such as pesticides, and many other challenges. Many EPA brownfield grants have been awarded to communities with less than 25,000 people. |
| Brownfields are an environment-only issue, or an EPA-only problem. | While brownfields by definition involve real or perceived environmental contamination, the solutions to brownfields problems almost always involve much broader issues including economic reuse, neighborhood improvement, infrastructure and transportation capacity, job creation, tax incentives, crime prevention, and many other approaches. Successful brownfield reuse generally occurs when economic and community development issues are addressed along with contamination concerns. The multidisciplinary nature of brownfields is one reason that more than 20 federal agencies, and a broad range of state, local, private and nonprofit entities, are now involved in brownfields revitalization. |

(American Planning Association, 2012, pg. 25)

## *Fig 1.3. Benefits of Building Urban Farms on Former Brownfields*

***ECONOMIC***

- Provide income for farmers as well as landowners
- Strengthen the local economy
- Create employment opportunities
- Decrease public land maintenance costs
- Increase local employment opportunities and generates income
- Capitalize on underused resources (e.g. rooftops, roadsides, utility right of ways, vacant property)
- Increase property values

***ENVIRONMENTAL***

- Improve urban biodiversity and species preservation (e.g. microorganisms, insects, birds, reptiles and animals)
- Contribute to urban environmental management
- Decrease and convert waste into a productive agricultural resource or input (e.g. composting of edible and inedible plants, irrigation of treated wastewater, graywater reuse)
- Offer additional open space to residents of urban areas
- Reduce heat island affect in urban areas
- Reduce amount of impervious surfaces in urban areas (e.g. stormwater management)
- Improve the health of natural systems

***SOCIAL***

- Increase access to fruits and vegetables, especially in low-income areas that have poor access to affordable, healthful foods
- Provide opportunities for nutrition education and other public health programming to improve nutrition knowledge, attitudes, and dietary intake
- Provide opportunities for experiential learning of how to grow, prepare, and eat fruits and vegetables
- Foster community building and increased social interaction
- Reduce human contact with contamination, thereby improving public health

(American Planning Association, 2012, pg. 39)

***Table 1.1. Phytoremediation at Superfund Sites***

| Site Name, State | Date Planted | Plant | Contaminant/Matrix |
|---|---|---|---|
| Carswell Site, TX | Spring 1996 | Eastern cottonwood tree | TCE/groundwater at 4-12 feet |
| Aberdeen Proving Grounds, MD | Spring 1996 | Hybrid poplar trees | TCE/groundwater |
| Edward Sears Site, NJ | Fall 1996 | Hybrid poplar trees | TCE/groundwater at 8 feet |
| Iowa Army Ammunition Depot, IA | Spring 1997 | Wetland and terrestrial plants | TNT/soil and pond water |
| Fort Wainwright, AK | Spring 1997 | Felt leaf willow | Pesticides/soil and groundwater |
| Kaufman & Minteer, NJ | Spring 1997 | Hybrid poplar trees | PCE/groundwater |
| Calhoun Park, SC | Fall 1998 | Local landscaping plants | PAH/groundwater at 1-4 feet |
| Solvent Recovery Systems of New England, CT | Spring 1998 | Hybrid poplar trees | Mixed solvents/groundwater |
| Twin Cities Army Ammunition Plant, MN | Spring 1998 | Corn, Indian mustard | Metals/soil |
| Bofors-Nobel, MI | Planting scheduled | Various trees and wetland plants | Residual sludge in waste lagoons |
| Del Monte, HI | Spring 1998 | Koa haole | Pesticides/soil and groundwater |
| INEEL, ID | Spring 1999 | Kochia, willow | Cesium, mercury in soil |

(Environmental Protection Agency, 2000, pg. 8)

***Table 1.2. Estimates of Phytoremediation Costs Versus Costs of Established Technologies***

| Contaminant | Phytoremediation Costs | Estimated Cost using Other Technologies | Source |
|---|---|---|---|
| Metals | \$80 per cubic yard | \$250 per cubic yard | Black (1995) |
| Site contaminated with petroleum hydrocarbons (site size not disclosed) | \$70,000 | \$850,000 | Jipson (1996) |
| 10 acres lead contaminated land | \$500,000 | \$12 million | Plummer (1997) |
| Radionuclides in surface water | \$2 to \$6 per thousand gallons treated | none listed | Richman (1997) |
| 1 hectare to a 15 cm depth (various contaminants) | \$2,500 to \$15,000 | none listed | Cunningham et al. (1996) |

(Chappell, 1997, pg.5)

***Table 1.3. Estimated Cost Savings Through the Use of Phytoremediation Rather Than Conventional Treatment***

| Contaminant and Matrix | Phytoremediation | | Conventional Treatment | | Projected Savings |
|---|---|---|---|---|---|
| | Application | Estimated Cost | Application | Estimated Cost | |
| Lead in soil (1 acre)[a] | Extraction, harvest, and disposal | \$150,000 -\$250,000 | Excavate and landfill | \$500,000 | 50-65 percent |
| Solvents in groundwater (2.5 acres)[b] | Degradation and hydraulic control | \$200,000 for installation and initial maintenance | Pump and treat | \$700,000 annual operating cost | 50 percent cost saving by third year |
| Total petroleum hydrocarbons in soil (1 acre)[c] | In-situ degradation | \$50,000 - \$100,000 | Excavate and landfill or incinerate | \$500,000 | 80 percent |

(Environmental Protection Agency, 2001, *Brownfields Technology Primer*, pg. 21)

***Table 1.4. Advantages and Disadvantages of Phytoremediation Technology***

| *Type of Phytoremediation* | *Advantages* | *Disadvantages* |
|---|---|---|
| Phytoextraction by trees | High biomass production | Potential for off-site migration and leaf transportation of metals to surface<br>Metals are concentrated in plant biomass and must eventually be disposed |
| Phytoextraction by grasses | High accumulation growth rate | Low biomass production; slow process<br>Metals are concentrated in plant biomass and must eventually be disposed |
| Phytoextraction by crops | High biomass and increased growth rate | Potential threat to food chain through ingestion by herbivores<br>Metals are concentrated in plant biomass and must eventually be disposed |
| Phytostabilization | No disposal of contaminated biomass required | Remaining liability issues, including maintenance for indefinite period of time |
| Phytodegradation in the rhizosphere | No disposal of contaminated soil | Limited to hydrocarbons only |
| Phytovolatilization | Limited application (As, Hg) | Possibility of releasing toxins to the atmosphere. Permit may be required |

(Pichtel, 2007, pg. 344)

## *Fig 2.1. Summary of Federal Brownfields Finance Programs*

**U.S. ENVIRONMENTAL PROTECTION AGENCY**

### ***Brownfields Assessment Grants***

Website: http://www.epa.gov/brownfields/assessment_grants.htm

- Grants to inventory, characterize, assess, and conduct planning and community involvement related to brownfield sites.
- Maximum of $200,000 grant for each of hazardous substances and petroleum product contaminants.
  - Waiver available for up to $350,000 for each under certain conditions
  - Can be used for a single specific site or community-wide.
- Eligible entities include state, local, and tribal governments and their agencies.
- Annual competitive grant application and review process.
- Funds should be used within three years of receipt, quarterly reporting to USEPA required.

### ***Brownfields Cleanup Grants***

Website: http://www.epa.gov/brownfields/cleanup_grants.htm

- Grants to carry out cleanup of brownfield sites.
- Maximum of $200,000 grant for each site.
- No entity can apply for more than three sites.
- Requires a 20 percent cost share.
- Eligible entities include state, local and tribal governments and their agencies, and nonprofit organizations.
- Annual competitive grant application and review process.
- Funds should be used within three years of receipt, quarterly reporting to USEPA required.

### ***Brownfields Cleanup Revolving Loan Fund***

Website: http://epa.gov/brownfields/rlflst.htm

- Grants for the purpose of establishing local revolving loan funds that provide low or no-interest loans to eligible parties to carry out assessment and cleanup at brownfield sites within the community.
- Maximum loan size and other terms are set by the local Revolving Loan Fund.
- Loan recipients can be private developers, nonprofits, and others as determined by local Revolving Loan Fund.

### ***Brownfields Tax Incentive***

Website: http://www.epa.gov/brownfields/tax/index.htm

- Deduct all costs of cleanup against federal income in the year costs were incurred, rather than spreading them out over a period of years.
- Property must be owned by the taxpayer incurring these expenses, and reuse must be for a trade, business, or production of income.
- No dollar maximum.

**DEPARTMENT OF HOUSING AND URBAN DEVELOPMENT**

### ***Brownfields Economic Development Initiative (BEDI)***

Website: http://hud.gov/offices/cpd/economicdevelopment/programs/bedi/index.cfm

- BEDI grants must be used in conjunction with Section 108 loan guarantee.
- Total of $10 million available nationally; maximum of $1 million per grant awarded.
- Minimum ratio of $1 loan guarantee required for each $1 BEDI grant, much higher ratio recommended.

(American Planning Association, 2012, pg. 88)

## *Table 2.2. Potential Brownfield Stakeholders*

| ***GOVERNMENT*** | ***COMMUNITY*** | ***PRIVATE SECTOR*** |
|---|---|---|
| • Elected officials<br>• Environmental regulators (DEQ, EPA, others)<br>• City planning, economic development, public works, and transportation authorities<br>• Regional planning authorities | • Community residents<br>• Neighborhood residents in close proximity to the site<br>• Neighborhood associations<br>• Environmental justice groups<br>• Community development corporations<br>• Youth organizations<br>• Faith-based organizations | • Property owners<br>• Buyers/end users<br>• Real estate developers<br>• Real estate brokers<br>• Attorneys<br>• Environmental consultants<br>• Remediation contractors<br>• Financial lenders<br>• Insurance providers<br>• Humanitarian organizations |

**ROLES AND INTERESTS OF BROWNFIELD STAKEHOLDERS**

| ***STAKEHOLDER*** | ***EXAMPLES*** | ***ROLE*** | ***INTEREST*** |
|---|---|---|---|
| ***PROPERTY OWNER*** | | Sell or develop the property | • Wants to receive a fair value for property depending on the extent of environmental contamination<br>• Wants to manage any liability concerns upfront |
| ***PUBLIC SECTOR STAKEHOLDERS*** | • Local government<br>• Community groups<br>• EPA grant recipients<br>• Nonprofit organizations | Redevelop the property from a community and economic development perspective | • Want to see the project succeed in terms of revitalizing blighted properties and generating economic growth<br>• May want the property's cleanup and reuse to enhance the community's image |
| ***PRIVATE SECTOR STAKEHOLDERS*** | • Investors<br>• Lenders<br>• Developers<br>• Insurers | Provide resources to develop the property | • Want to see the project succeed in terms of revitalizing blighted properties and generating economic growth<br>• Want to earn an appropriate return on investment<br>• May want to tie the property redevelopment into a larger redevelopment plan for the neighborhood or community |
| ***OTHER PARTIES*** | • Attorneys<br>• Environmental consultants<br>• State and federal regulators | Provide technical, regulatory, or other guidance | • Want to ensure that the property is cleaned up and safe for appropriate levels of use and reuse<br>• Want to alleviate future environmental concerns on the property |

(American Planning Association, 2012, pg. 54-55)

### *Table 2.3. Common Public Participation Techniques*

| **SHARING INFORMATION** | |
|---|---|
| Bill Stuffers | Information flyer included with monthly utility bill |
| Briefings | Use regular meetings (neighborhood associations, faith-based groups, social and civic clubs) to provide an opportunity to inform and educate. |
| Community Events | A good way to introduce the project or the organization to the community, provide information, and gain support |
| Feature Story | Focused stories on project related issues in neighborhood or church newsletters or even city papers |
| Information Kiosks | A station where project information is available |
| Listservs and E-mail Addresses | Anyone can register to receive any messages sent to the listserv. A dedicated e-mail address will allow stakeholders to contact project leaders with questions and feedback. |
| Newspaper Inserts | A "fact sheet" within the local newspaper |
| Printed Public Information Materials | Fact Sheets, Newsletters, Brochures, Issue Papers, Progress Reports, Direct Mail Letters |
| Responsiveness Summaries | A form of documentation that provides feedback to the public regarding comments received and how they are being incorporated |
| Technical Information Contacts | Providing access to technical expertise to individuals and organizations |
| Outreach Materials | Visual aides, displays, and events outreach materials are useful to bring to community events and meetings |
| Site Visit/Tour | A site tour will allow community members to visualize the changes that will take place on site. |
| Website | Provides information about the project and potentially serves as a venue for illiciting feedback from community residents |
| **COMPILING AND PROVIDING FEEDBACK** | |
| Comment Forms | Mail-in forms often included in fact sheets and other project mailings to gain information on public concerns and preferences. Can also be web-based. |
| Toll-free Hotline | A central number that concerned citizens can call to get information or to express concerns about the project |
| Community Facilitators | Use qualified individuals in local community organizations to conduct project outreach. |
| In-Person Surveys | One-on-one "focus groups" with standardized questionnaire or methodology such as "stated preference" |
| Internet Surveys/Polls | Free online survey software (such as Survey Monkey) allows a user to develop and publish a custom survey online. |
| Interviews | One-to-one meetings with stakeholders to gain information for developing or refining public involvement and consensus-building programs |
| Mailed Surveys & Questionnaires | Inquiries mailed randomly to sample population to gain specific information for statistical validation |
| Photovoice | A method of community engagement that uses photography. Community members are encouraged to walk around their community and document the physical components they think are important as well as the elements they would like to change. |
| **BRINGING PEOPLE TOGETHER** | |
| Charrettes | Intensive session where participants design project features |
| Computer-Assisted Meetings | Any sized meeting when participants use interactive computer technology to register opinions |
| Deliberative Dialogues | A systematic dialogic process that brings people together as a group to make choices about difficult, complex public issues where there is a lot of uncertainty about solutions and a high likelihood of people polarizing on the issue. The goal of deliberation is to find where there is common ground for action. |
| Deliberative Polling Processes | Measures informed opinion on an issue |
| Fairs & Events | Central event with multiple activities to provide project information and raise awareness |
| Focus Groups | Message testing forum with randomly selected members of target audience. Can also be used to obtain input on planning decisions |
| Ongoing Advisory Groups | A group of representative stakeholders assembled to provide public input to the planning process. May also have members from the project team and experts. |
| Open Houses/Public Meetings | Encourages involvement from the public at large. |
| Task Forces – Expert Committee | A group of experts or representative stakeholders formed to develop a specific product or policy recommendation |
| Town Meetings | A group meeting format where people come together as equals to share concerns. |
| Workshops | An informal public meeting that may include presentations and exhibits but ends with interactive working groups |

(American Planning Association, 2012, pg. 64)

## *Table 2.4. Capabilities and Intellectual Properties of Dedicated Phytoremediation Companies in the U.S. as of 2002*

| Company and date of creation (URL) | Plants and pollutants | Phytotechnology | Protection of intellectual property rights | Research connections |
|---|---|---|---|---|
| Applied Natural Sciences, Inc., 1993 (www.treemediation.com) | Hybrid poplars and willow (Salicaceae) to treat chlorinated solvents, pesticides, other organic contaminants, nutrients, and metals | Deep planting, hydraulic control, transformation, and rhizodegradation | Utility patents for deep planting (TreeWell® and TreeMediation®) (U.S. #5 829 191 and #5 829 192) | U.S. Department of Energy, Argonne National Laboratory |
| Applied PhytoGenetics, Inc., 1999 (www.appliedphytogenetics.com) | Naturally occurring plants for organic contaminants, transgenic plants for elemental contaminants | Transformation, extraction, and hyperaccumulation | Patent-protected mercury phytoremediation (U.S.#5 668 294 and U.S.#5 965 796) and trade secrets | University of Georgia |
| Ecolotree, Inc., 1990 (www.ecolotree.com) | Hybrid poplar trees (*Populus* spp.), legumes, and grasses to treat organic contaminants, landfill leachates, agrochemical spills, contaminated soil and groundwater, brownfields, municipal and industrial wastewater, and animal feed lot drainage, and to stabilize stream riparian areas | Hydraulic control, vegetative covers, phytoirrigation, and riparian buffers | Utility patents for vegetative capping, ECap® (U.S. #5 947 041) and EBuffer® (U.S. #6 250 237) plus trade secrets | University of Iowa and Oregon State University |
| Ecoscience, Inc., 1978 (www.ecoscnc.com) | Ecological restoration and wetlands to treat wastewater | Stabilization, rhizodegradation, and transformation | Development transgenic plants | |
| Edenspace Systems Corporation, acquired Phytotech 1999, which began 1993 (www.edenspace.com) | Hyperaccumulators [Indian mustard (*Brassica juncea*) and sunflower (*Helianthus annuus*)] to extract metals, arsenic, and radionuclides | Phytoextraction, hyperaccumulation, phytostabilization, and rhizofiltration | 11 patents for phytoextraction (U.S. #05 364 451), hyperaccumulation, and rhizofiltration; various applications pending; and seeds, soil amendments, hyperaccumulation inducing agents | Rutgers University |
| Lemna Technologies, Inc., 1983 (www.lemnatechnologies.com) | Duckweed (*Lemna* spp.) for wastwater treatment | Plant lagoons that remove nutrients, organic wastes, and solids | Patents dating to 1985 for LemTec® | |
| Living Technologies, Inc., ca. 1992 (www.living machines.com) | Aquatic plants for wastewater treatment in reactors | Stimulated bioremediation, transformation, and rhizofiltration | Unique bioreactor design, Living Machine® | |
| Phytokinetics, Inc., 1994 (www.phytokinetics.com) | Trees and grasses to treat organic contaminants, and nutrients | Rhizodegradation, hydraulic control, and transformation | Trade secrets | Utah State and other universities |
| Planteco, 2000 (www.planteco.com) | Trees, grasses, and aquatic plants to treat soils and groundwater contaminated with chlorinated solvents, perchlorate, and hydrocarbons | Hydraulic control, transformation, and rhizodegradation | Trade secrets and unique microbial mat bioreactors | University of Gengia |
| Sustainable Strategies, 1973 (www.ecological-engineering.com) | Aquatic plants in greenhouses or water gardens for treatment of domestic, industrial, or animal wastewaters | Transformation, rhizolfdegradion, and rhizofiltration | Patented Solar Aquatics System® and wastewater garden, washwater garden, and Bamboo Forest Manure Management System | Tufts University and University of Toronto |
| Thomas Consultants, Inc., 1989 (www.thomasconsultants.com) | Hybrid poplars (*Populus* spp.) to treat metals, organic contaminants, and nutrients | Nutrient uptake and stabilization | Trade secrets | |
| TreeTec Environmental Corp., 1995 (www.treetec.com) | Salicaceae for soil, water, and air decontamination | Phytoirrigation and carbon dioxide removal from air | Selection of varieties, proprietary Sagitta trees, and extensive inventory of hybrids | Washington State University |

(McCutcheon, 2003, pg. 99-100)

***Table 2.5. Capabilities and Intellectual Properties of Dedicated Phytoremediation Companies in the U.S. as of 2002, Continued; Companies in Canada and Europe***

**TABLE 3-2 Capabilities and Intellectual Properties of Dedicated Phytoremediation Companies in the U.S. as of 2002**

| Company and date of creation (URL) | Plants and pollutants | Phytotechnology | Protection of intellectual property rights | Research connections |
|---|---|---|---|---|
| Verdant Technologies, Inc., 1996 (www.verdanttech.com) | Trees to treat chlorinated solvents and organic contaminants | Transformation | Patents pending and trade secrets | University of Washington, University of South Carolina, and U.S. Department of Energy Savannah River Ecology Laboratory |
| Viridian Environmental, LLC, 1998 | Hyperaccumulators to remove metals | Phytomining and stabilization | Utility patent by assignment | U.S. Department of Agriculture, University of Maryland, and University of Sheffield |
| Wolverton Environmental Services, Inc., ca. 1992 (www.wolvertonenvironmental.com) | Reeds and aquatic plants for wastewater treatment and indoor plants for air purification | Transformation, rhizodegradation, and rhizofiltration | Patented Micro-Agro℠ process and other patents | U.S. National Aeronautics and Space Administration |

***Dedicated Phytoremediation Companies in Canada and Europe***

| Company and date of startup (URL) | Plants | Pollutants and waste | Phytotechnology |
|---|---|---|---|
| *Canada* | | | |
| Abydoz Environmental Inc., 1997 (www.abydoz.com) | Reeds (*Phragmites* spp.) and other wetland plants | Domestic and industial wastewater | Patented wetlands: Kickuth BioReactor℠ and PhytoKlare℠ |
| *Europe* | | | |
| BioPlanta GmbH, Germany, 1991 (www.bioplanta-leipzig.de) | Reeds (*Phragmites* spp.) and other plants | Wastewater, sludge, phenolic coal wastes, animal waste, and mine wastes | Wetland treatment, vegetative capping, revegetation, and rhizodegradation |
| Consulagri S.r.l., Italy (consugri@tin.it) | Not specified | Metals | Extraction |
| Eco-Pest S.L., Spain (www.ecopest-sl.com) | Aquatic plants | Domestic and industrial wastewaters | Extraction and transformation in bioreactors with water-immersed roots (Living Machine℠) |
| Körte-Organica Ecotechnologies, Hungary, 1989 and 1998 (www.korteorganica.hu) | Aquatic plants | Industrial wastewater and groundwater | Extraction and transformation in bioreactors with water-immersed roots (Living Machine℠) |
| Oceans ESU, U.K., 1991 (www.oceans-esu.com) | Reed (*Phragmites* spp.) beds | Industrial, agricultural, and domestic wastewater and runoff | Wetland treatment |

*Note*: Data obtained from Glass (1999, 2001b), and company web sites.

(McCutcheon, 2003, pg. 101-102)

### *Table 2.6. Common Contaminants and Remediation Technologies*

| TYPE OF SITE | COMMON CONTAMINANTS | TECHNOLOGY APPLICATIONS |
|---|---|---|
| Agriculture | Volatile organic compounds (VOCs), pesticides, halogenated VOCs, metals | Bioremediation, soil vapor extraction (SVE), soil flushing |
| Dry cleaning | Halogenated VOCs, solvents | SVE, chemical oxidation, air sparging |
| Automotive repair | VOCs, semicolatile organic compounds (SVOCs), metals | Bioremediation, SVE, air sparging |
| Metal finishing | VOCs, metals, acids | Chemical oxidation, SVE, air sparging, soil flushing, permeable reactive barriers (PRBs), bioremediation |
| Iron and steel mill sites | Metals, acids, ammonia, SVOCs, VOCs | Chemical oxidation, SVE, air sparging, thermal description, PRBs, bioremediation |
| Wood pulp and paer manufacturing | Dioxin, halogenated VOCs, acids | Chemical oxidation, SVE, air sparging, electrical resistance vitrification, thermal desorption |
| Wood preserving | Light nonaqueous phase liquids (LNAPLs), metals, dioxin, halogenated SVOCs | Soil flushing, bioslurping, electrical resistance vitrification, chemical oxidation, PRBs |
| Semiconductor manufacturing | Metals, VOCs, halogenated VOCs, solvents | Bioremediation, SVE, phtoremediation, soil flushing, multiphase extraction (MPE), electrical resistance vitrification |
| Research and educational institutions | Inorganic acids, solvents, metals, pesticides | Soil flushing, chemical oxidation, PRBs, electromigration, electrical resistance vitrification |
| Railroad yards | Petrochemicals, VOCs, solvents | Soil flushing, bioslurping, bioremediation, chemical oxidation |
| Paint/ink manufacturers | Metals, VOCs, solvents, halogenated VOCs | SVE, MPE, phytoremediation, electrical resistance vitrification, electromigration, thermal description, soil flushing |
| Hospitals | Radionuclides, VOCs, solvents, metals | Electrical resistance vitrification, MPE, electromigration, PRBs |
| Landfills | Metals, VOCs, halogenated SVOCs, solvents, pesticides | Electrical resistance vitrification, bioremediation, soil flushing, electromigration |
| Electroplating operations | Metals | Soil flushing, chemical oxidation, PRBs, electromigration, phytoremediation |
| Glass manufacturing | Metals, inorganics | Soil flushing, chemical oxidation, PRBs, electromigration, phytoremediation |
| Gas station or petroleum refining | Fuels, nonaqueous phase liquids (NAPLs), petroleum hydrocarbons | Bioslurping, thermal desorption, bioremediation, MPE |

(American Planning Association, 2012, pg. 71)

### *Table 2.7. Distribution of Trace Elements in World Soils*

| Element | Common Range | Average |
|---|---|---|
| | mg/kg | |
| Arsenic (As) | 1–50 | 5 |
| Cadmium (Cd) | 0.01–0.70 | 0.06 |
| Chromium (Cr) | 1–1,000 | 100 |
| Lead (Pb) | 2–200 | 10 |
| Mercury (Hg) | 0.01–0.3 | 0.03 |
| Barium (Ba) | 100–3,000 | 430 |
| Boron (B) | 2–100 | 10 |
| Copper (Cu) | 2–100 | 30 |
| Manganese (Mn) | 20–3,000 | 600 |
| Nickel (Ni) | 5–500 | 40 |
| Selenium (Se) | 0.1–2 | 0.3 |
| Silver (Ag) | 0.01–5 | 0.05 |
| Tin (Sn) | 2–200 | 10 |
| Zinc (Zn) | 10–300 | 50 |

(Pichtel, 2007, pg. 28)

### *Table 2.8. Numbers of Known Plant Hyperaccumulators for Eight Heavy Metals and the Families in Which they are Most Often Found*

**Table 1.1**. Numbers of known plant hyperaccumulators for eight heavy metals and the families in which they are most often found.

| Element | No. | Families |
|---|---|---|
| Cadmium | 1 | Brassicaceae |
| Cobalt | 26 | Lamiaceae, Scrophulariaceae |
| Copper | 24 | Cyperaceae, Lamiacaeae, Poaceae, Scrophulariaceae |
| Manganese | 11 | Apocynaceae, Cunoniaceae, Proteaceae |
| Nickel | 290 | Brassicaceae, Cunoniaceae, Euphorbiaceae, Flacourtiaceae, Violaceae |
| Selenium | 19 | Fabaceae |
| Thallium* | 1 | Brassicaceae |
| Zinc | 16 | Brassicaceae, Violaceae |

*Leblanc *et al.* (1997).

(Brooks, 1998, pg. 4)

### *Table 2.9. Annual Metal Removal (kg/ha) by Plant Shoot Harvest in Relation to Biomass Yield (t/ha) and Metal Concentration in the Plant (ug/g)*

**Table 12.1**. Annual metal removal (kg/ha) by plant shoot harvests in relation to biomass yield (t/ha) and metal concentration in the plant ($\mu$g/g).

| Type of plant | Concentration | Yield | Removal |
|---|---|---|---|
| Non-hyperaccumulator | 50 | 5 | 0.25 |
| | 50 | 10 | 0.50 |
| | 50 | 15 | 0.75 |
| | 50 | 20 | 1.00 |
| | 50 | 25 | 1.25 |
| | 500 | 5 | 2.50 |
| | 500 | 10 | 5.00 |
| | 500 | 15 | 7.50 |
| | 500 | 20 | 10.00 |
| | 500 | 25 | 12.50 |
| Hyperaccumulator | 1000 | 5 | 5.00 |
| | 10,000 | 5 | 50.00 |
| | 20,000 | 5 | 100.00 |

(Brooks, 1998, pg. 262)

***Fig 2.1. Acceptable Contaminant Levels and Remediation Processes***

| CONTAMINANT | | MAXIMUM LEVELS OF CONTAMINANT FOR: Multi Family Housing.. ..Recreation..Park | Single Family Houses.. Gardening..Playground | Farming Animals.. ..Growing Food | |
|---|---|---|---|---|---|
| As | Arsenic | 16ppm | 16ppm | 13ppm | Often found in lead-acid batteries, light-emitting diodes, paints, dyes, metals, pharmaceuticals, pesticides, herbicides, soaps, and semiconductors. |
| Cr | Chromium | 180ppm | 36ppm | 30ppm | PHYTOEXTRACTION |
| Pb | Lead | 400ppm | 400ppm | 63ppm | PHYTOSTABILIZATION |
| Hg | Mercury | 0.81ppm | 0.81ppm | 0.18ppm | PHYTOSTABILIZATION |
| PCB | Polychlo-rinated biphenyls | 1ppm | 1ppm | 0.1ppm | PCBs appear as colorless to light yellow oily liquids or waxy solids. They accumulate in fish and marine mammals at much higher levels than in sediments and water. |
| TCE | Trichloro-ethlene | 21ppm | 10ppm | 0.47ppm | PHYTODEGRADATION |
| MTBE | Methyl tertiary butyl ether | 100ppm | 62ppm | 0.93ppm | Typically used as a fuel additive in gasoline. Common in areas that were exposed to leakage from the gasoline storage and distribution systems. |
| DDT | Dichloro-phenyltri-chloroethane | 7.9ppm | 1.7ppm | 0.0033ppm | |
| PCP | Pentachloro-pheno | 6.7ppm | 2.4ppm | 0.8ppm | PHYTODEGRADATION |

(Environmental Protection Agency, 2010, pg. 8)

***Table 2.10. Summary of Physical Remediation Techniques***

| | *Excavation* | *Geotextiles* | *Soil washing* | *Soil vapor extraction* |
|---|---|---|---|---|
| **Access** | yes | yes | yes | yes |
| **Cost ($CAD)** | $5000-<br>$10 000 | <$1000<br>+excavation<br>costs | $1000-<br>$5000 | $10 000+ |
| **Timeframe** | short<br><1 season | short<br><1 season | short<br><1 season | short<br><1 season |
| **Effectiveness for UA** | 1 | 2 | 1 | 1 |
| **Environmental Effects** | energy use<br>air pollution<br>disposal | energy use<br>air pollution<br>disposal | energy use<br>air pollution<br>disposal | energy use<br>air pollution<br>disposal |

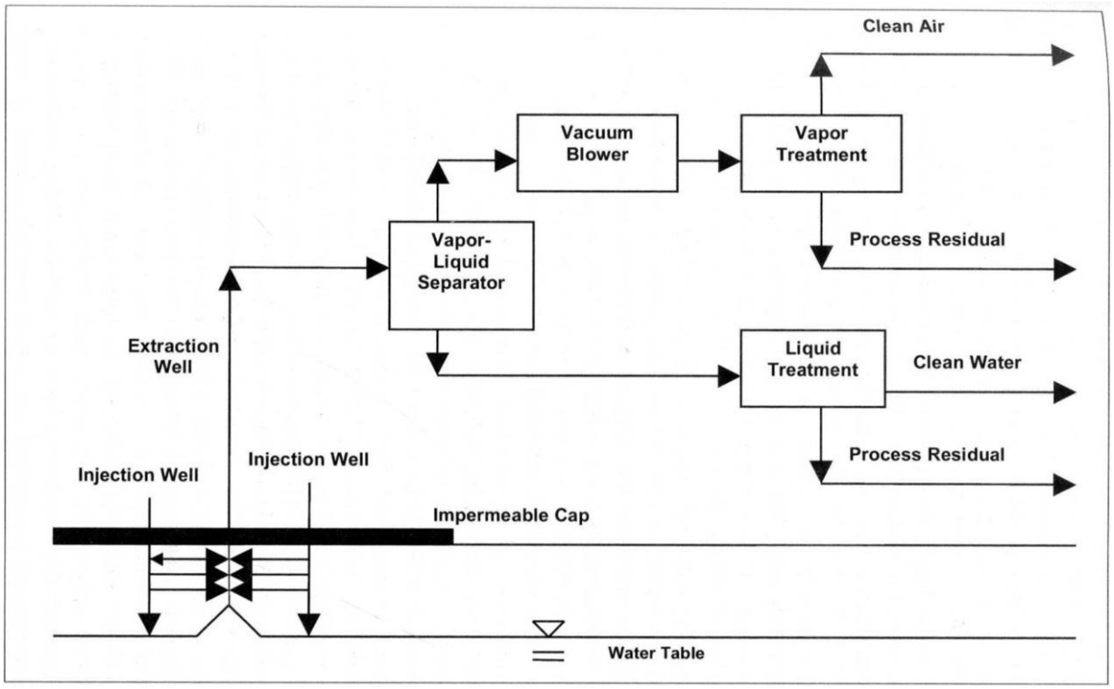
(Heinegg, 2002, pg. 7)

***Table 2.11 Summary of Bioremediation Techniques***

| | *Microbial remediation* | *Phyto-remediation* | *Fungal remediation* | *Compost remediation* |
|---|---|---|---|---|
| **Access** | yes | yes | no | yes |
| **Cost ($CAD)** | <$1000 | <$1000 | n/a | <$1000 |
| **Timeframe** | short<br><1 year | 2-5+ years | n/a | short<br><1 season |
| **Effectiveness for UA** | 2 | 2 | 3 | 2-3 |
| **Environmental Effects** | potential<br>metal<br>toxicity | disposal<br>of toxic<br>plants | potential<br>metal<br>toxicity | none |

(Heinegg, 2002, pg. 9)

***Fig 2.2. Schematic View of a Soil Vapor Extraction System***




(Pichtel, 2007, pg. 219)

***Table 2.12. Types of Phytoremediation Systems***

| Treatment Method | Mechanism | Media |
|---|---|---|
| Rhizofiltration | Uptake of metals in plant roots | surface water and water pumped through troughs |
| Phytotransformation | Plant uptake and degradation of organics | surface water, groundwater |
| Plant-Assisted Bioremediation | Enhanced microbial degradation in the rhizosphere | soils, groundwater within the rhizosphere |
| Phytoextraction | Uptake and concentration of metals via direct uptake into plant tissue with subsequent removal of the plants | soils |
| Phytostabilization | Root exudates cause metals to precipitate and become less bioavailable | soils, groundwater, mine tailings |
| Phytovolatilization | Plant evapotranspirates selenium, mercury, and volatile organics | soils, groundwater |
| Removal of organics from the air | Leaves take up volatile organics | air |
| Vegetative Caps | Rainwater is evapotranspirated by plants to prevent leaching contaminants from disposal sites | soils |

(Chappell, 1997, pg. 8)

## *Table 2.13. Types of Plants, Contaminants, and Media*

| Type of Contaminant | Medium | Type of Plant: Alfalfa | Alyssum | Bald cypress | Black locust | Cottonwood | Grasses | Hybrid poplars | Indian mustard | Pennycress | Red Mulberry | Stonewort | Sunflower | Water hyacinth | Willow |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Organic | Soil | | | ▲<br>PD<br>RD | | | ▲<br>RD | ▲<br>PD<br>RD | | | ▲<br>RD | ▲<br>PD | | | ▲<br>PD<br>RD |
| | Sediment | | | ▲<br>PD<br>RD | | | ▲<br>RD | ▲<br>PD<br>RD | | | ▲<br>RD | ▲<br>PD | | | ▲<br>PD<br>RD |
| | Groundwater | | | ▲<br>PD | | ▲<br>HC | | ▲<br>HC<br>PD | | | | ▲<br>PD | | | ▲<br>HC<br>PD |
| Inorganic | Soil | ▲<br>PV | ▲<br>PE | | ▲<br>PV | | ▲<br>PS | ▲<br>PE<br>PS<br>PV | ▲<br>PE<br>PS<br>PV | ▲<br>PE | | | ▲<br>PE | | |
| | Sediment | ▲<br>PV | ▲<br>PE | | ▲<br>PV | | ▲<br>PS | ▲<br>PE<br>PS<br>PV | ▲<br>PE<br>PS<br>PV | ▲<br>PE | | | ▲<br>PE | | |
| | Groundwater | | | | | ▲<br>HC | | ▲<br>HC | ▲<br>RF | | | | ▲<br>RF | ▲<br>RF | ▲<br>HC |

▲ Plant is effective for the type of contamination and medium shown.
HC Hydraulic control
PD Phytodegradation
PE Phytoextraction
PS Phytostabilization
PV Phytovolatilization
RD Rhizodegradation
RF Rhizofiltration

(Environmental Protection Agency, 2001, *Brownfields Technology Primer,* pg. 8)

## *Table 2.14. Phytoremediation Overview*

| Mechanism | Process Goal | Media | Contaminants | Plants | Status |
|---|---|---|---|---|---|
| Phytoextraction | Contaminant extraction and capture | Soil, sediment, sludges | Metals: Ag, Cd, Co, Cr, Cu, Hg, Mn, Mo, Ni, Pb, Zn; Radionuclides: $^{90}Sr$, $^{137}Cs$, $^{239}Pu$, $^{238,234}U$ | Indian mustard, pennycress, alyssum sunflowers, hybrid poplars | Laboratory, pilot, and field applications |
| Rhizofiltration | Contaminant extraction and capture | Groundwater, surface water | Metals, radionuclides | Sunflowers, Indian mustard, water hyacinth | Laboratory and pilot-scale |
| Phytostabilization | Contaminant containment | Soil, sediment, sludges | As, Cd, Cr, Cu, Hs, Pb, Zn | Indian mustard, hybrid poplars, grasses | Field application |
| Rhizodegradation | Contaminant destruction | Soil, sediment, sludges, groundwater, | Organic compounds (TPH, PAHs, pesticides chlorinated solvents, PCBs) | Red mulberry, grasses, hybrid poplar, cattail, rice | Field application |
| Phytodegradation | Contaminant destruction | Soil, sediment, sludges, groundwater surface water | Organic compounds, chlorinated solvents, phenols, herbicides, munitions | Algae, stonewort, hybrid poplar, black willow, bald cypress | Field demonstration |
| Phytovolatilization | Contaminant extraction from media and release to air | Groundwater, soil, sediment, sludges | Chlorinated solvents, some inorganics (Se, Hg, and As) | Poplars, alfalfa black locust, Indian mustard | Laboratory and field application |
| Hydraulic control (plume control) | Contaminant degradation or containment | Groundwater, surface water | Water-soluble organics and inorganics | Hybrid poplar, cottonwood, willow | Field demonstration |
| Vegetative cover (evapotranspiration cover) | Contaminant containment, erosion control | Soil, sludge, sediments | Organic and inorganic compounds | Poplars, grasses | Field application |
| Riparian corridors (non-point source control) | Contaminant destruction | Surface water, groundwater | Water-soluble organics and inorganics | Poplars | Field application |

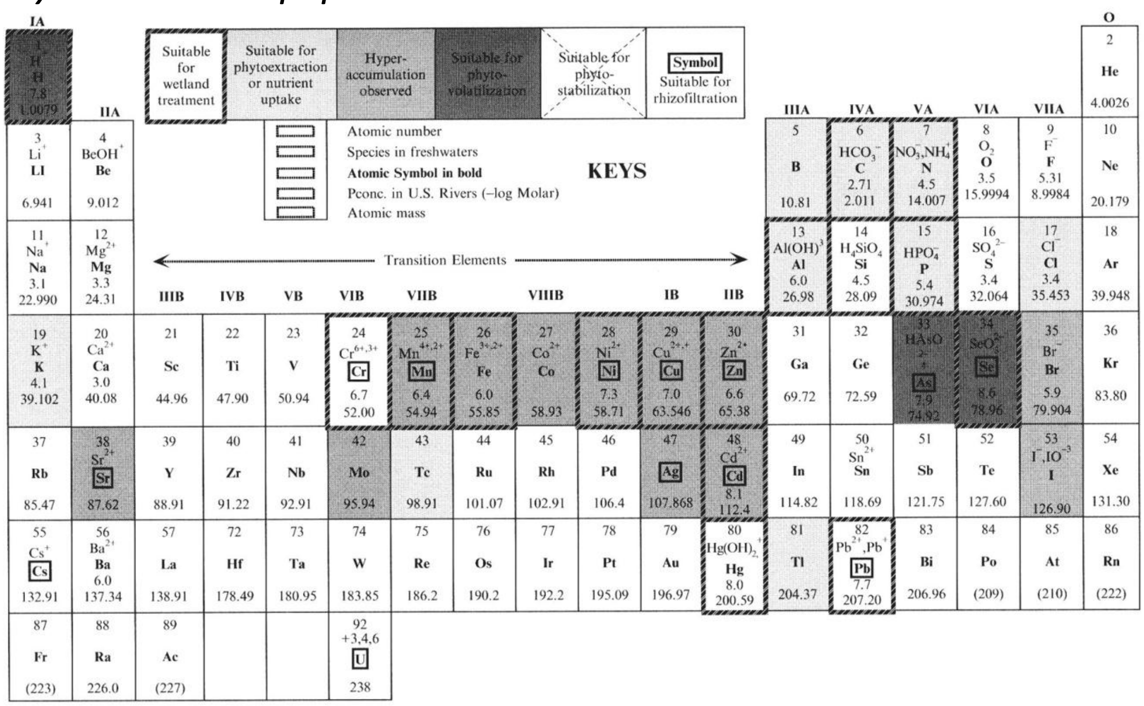
(Environmental Protection Agency, 2000, pg. 15)

***Table 2.15. Phytoremediation Applications***

| Mechanism | Contaminant | Media | Plant | Status | Reference |
|---|---|---|---|---|---|
| Degradation | Atrazine, nitrates | Surface Water | Poplar | Applied | Schnoor 1995a |
| Degradation | Landfill leachate | Groundwater | Poplar | Applied | Licht 1990 |
| Degradation | TCE | Groundwater | Poplar, cottonwood | Field demo | Rock 1997 |
| Degradation | TNT | Wetlands | Various | Field demo | Bader 1996<br>Carreira 1996<br>McCutcheon 1995 |
| Degradation | TPH | Soil | Grasses, crops | Field demo | Banks 1997<br>Drake 1997 |
| Extraction-Concentration in shoot | Lead | Soil | Indian mustard | Field demo | Blaylock 1997 |
| Extraction-Concentration in root | Uranium | Surface water | Sunflower | Field demo | Dushenkov 1997 |
| Extraction, Volatilization | Selenium | Soil, Surface Water | Various | Applied | Bañuelos 1996<br>Terry 1996 |

(Environmental Protection Agency, 2000, pg. 5)

***Fig 2.3. Elements for which Phytoextraction, Phytostabilization, and Phytovolitilization may be Possible Cleanup Options***



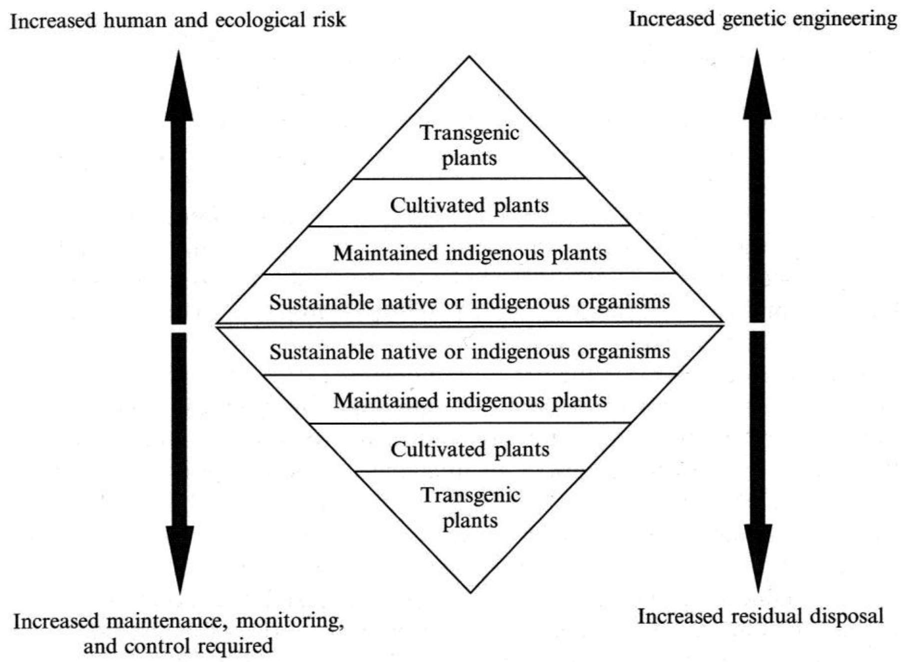

(McCutcheon, 2003, pg. 17)

*Table 2.16. Advantages and Limitations of Phytoremediation*

| Advantages of Phytoremediation | Limitations of Phytoremediation |
|---|---|
| *in situ* | Limited to shallow soils, streams, and groundwater |
| Passive | High concentrations of hazardous materials can be toxic to plants |
| Solar driven | Mass transfer limitations associated with other biotreatments |
| Costs 10% to 20% of mechanical treatments | Slower than mechanical treatments |
| Transfer is faster than natural attenuation | Only effective for moderately hydrophobic contaminants |
| High public acceptance | Toxicity and bioavailability of degradation products is not known |
| Fewer air and water emissions | Contaminants may be mobilized into the groundwater |
| Generate less secondary wastes | Potential for contaminants to enter food chain through animal consumption |
| Soils remain in place and are usable following treatment | Unfamiliar to many regulators |

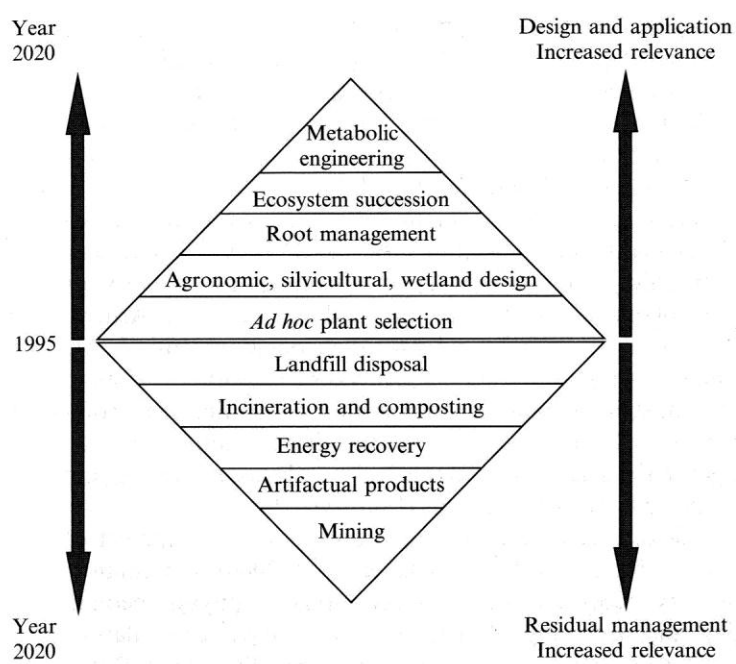
(Chappell, 1997, pg. 3)

***Fig 2.4. Relationship Between Plant Types and the Advantages and Disadvantages of use for Phytoremediation***




(McCutcheon , 2003, pg. 89)

***Fig 2.5. Needed Improvements in Pre-Harvest and Post-Harvest Strategies***




(McCutcheon, 2003, pg. 107)

*Table 2.17. Strengths and Weaknesses of Different Kinds of Plants Used in Phytoremediation Applications*

| Plant type | Applications[a] | Strong points[a] | Drawbacks | Final disposition |
|---|---|---|---|---|
| *Thlaspi*, *Alyssum*, and *Brassica* spp. | Phytoextraction and phytomining | Metal hyperaccumulation and metal tolerance (Brooks 1998) | Low adaptability and low biomass production; toxic metals can leach from fallen leaves, dead roots, and other plant parts. It may take more than 10 years to remediate a site (Salt *et al.* 1995) | Subjected to volume reduction by incineration or composting; disposed in hazardous waste landfills and economical recovery of metals by smelting |
| Grasses [*i.e.*, alfalfa (*Medicago sativa*)] and food crops | Stabilization and rhizodegradation | Rapid growth, processing of contaminants results in a modest plant contamination but the fibrous rooting, trace elements may serve as animal feed supplements (Anderson *et al.* 1993, Schnoor 1997) | Risk for accumulation of contaminants or by-products into food chain | Composting, and animal, feeding when contamination does not lead to toxicity |
| *Atriplex* and *Salicornia* | Salt extraction and volume reduction of oil-field brines | Salt tolerant plants may serve as animal feed and as a source of salt | Possibly invasive | Edible (animal feed and essential oils) or any disposal seems acceptable except on salt sensitive soils |
| Poplar (*Populus* spp.), willow (*Salix* spp.), and cottonwood (*Populus deltoides*) | Contaminant biotransformation, barrier for hydraulic containment, and vegetative cover for landfills and riparian buffers | Phreatophytic (takes water from aquifers), with rapid growth, deep rooting, and high transpiration rate | Long time required for biotransformation, with potential plant contamination and risks of food chain accumulation (Sandermann 1994) | Production of energy by short rotation coppice |
| Duckweed (*Lemma minor)* and pennywort (*Hydrocotyle* spp.) | Rhizofiltration and phytotransformation | Adapted to wetlands with rapid growth | Invasive in some settings | Collection by skimming and some feeding to animals is possible depending on contaminants |
| Reeds (*Phragmites* spp.), bamboo (*Bambusa* spp.), and cattails (*Typha* spp.) | Constructed wetlands | Adapted to wetlands with rapid growth | Invasive in some settings | Biomass collection for fuel, fiber, and paper production |

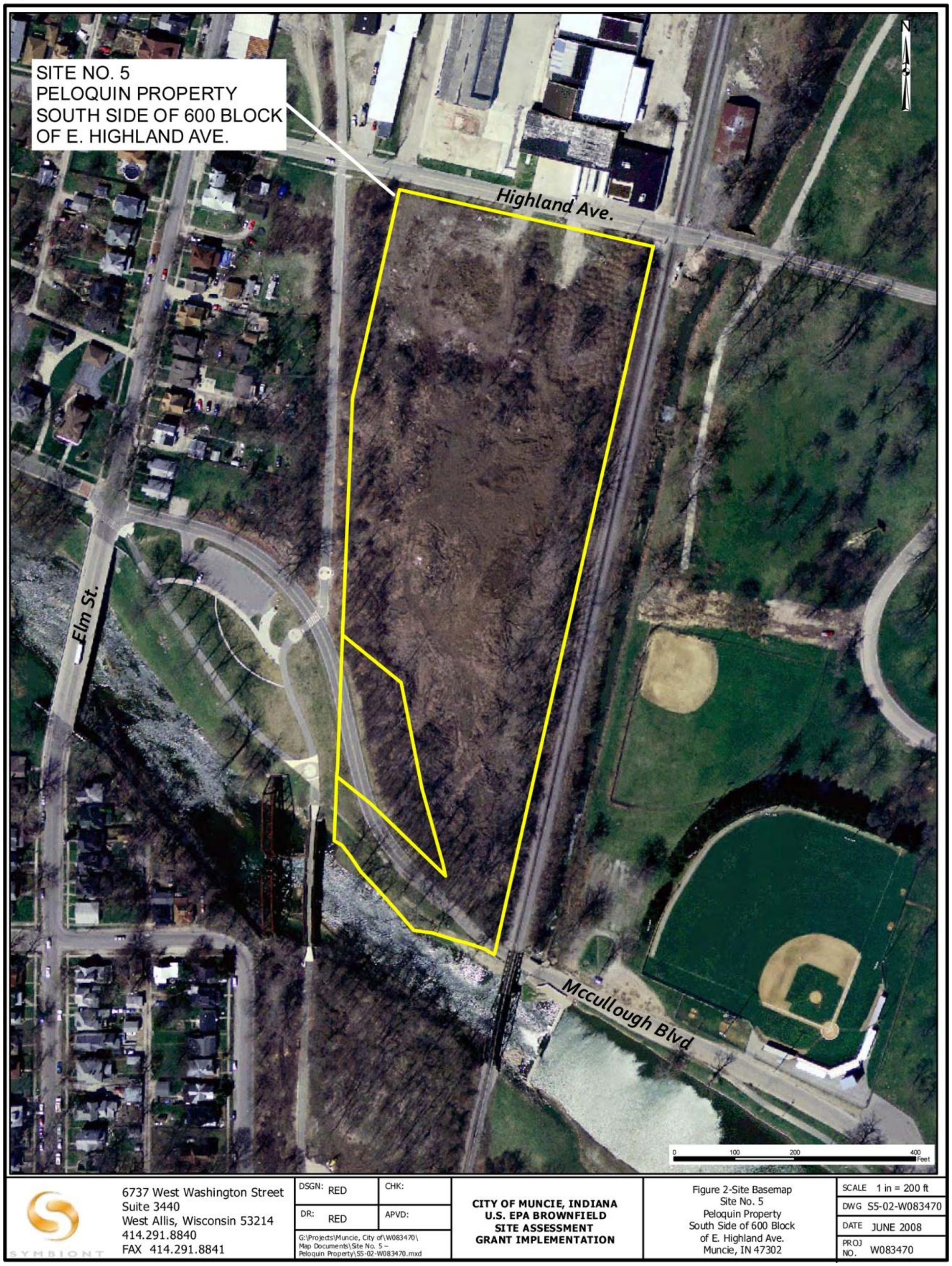
(McCutcheon, 2003, pg. 87-88)

*Table 2.18. Costs for Trees and Wells*

| Activity | Estimated Cost |
|---|---|
| Wholesale cost of trees (does not include delivery or installation costs) | \$8/tree for five-gallon bucket tree<br>\$0.20/tree for whips |
| 29 wells (including surveying, drilling, and testing) | \$200,000 |
| Subsurface fine biomass | \$60,000 |

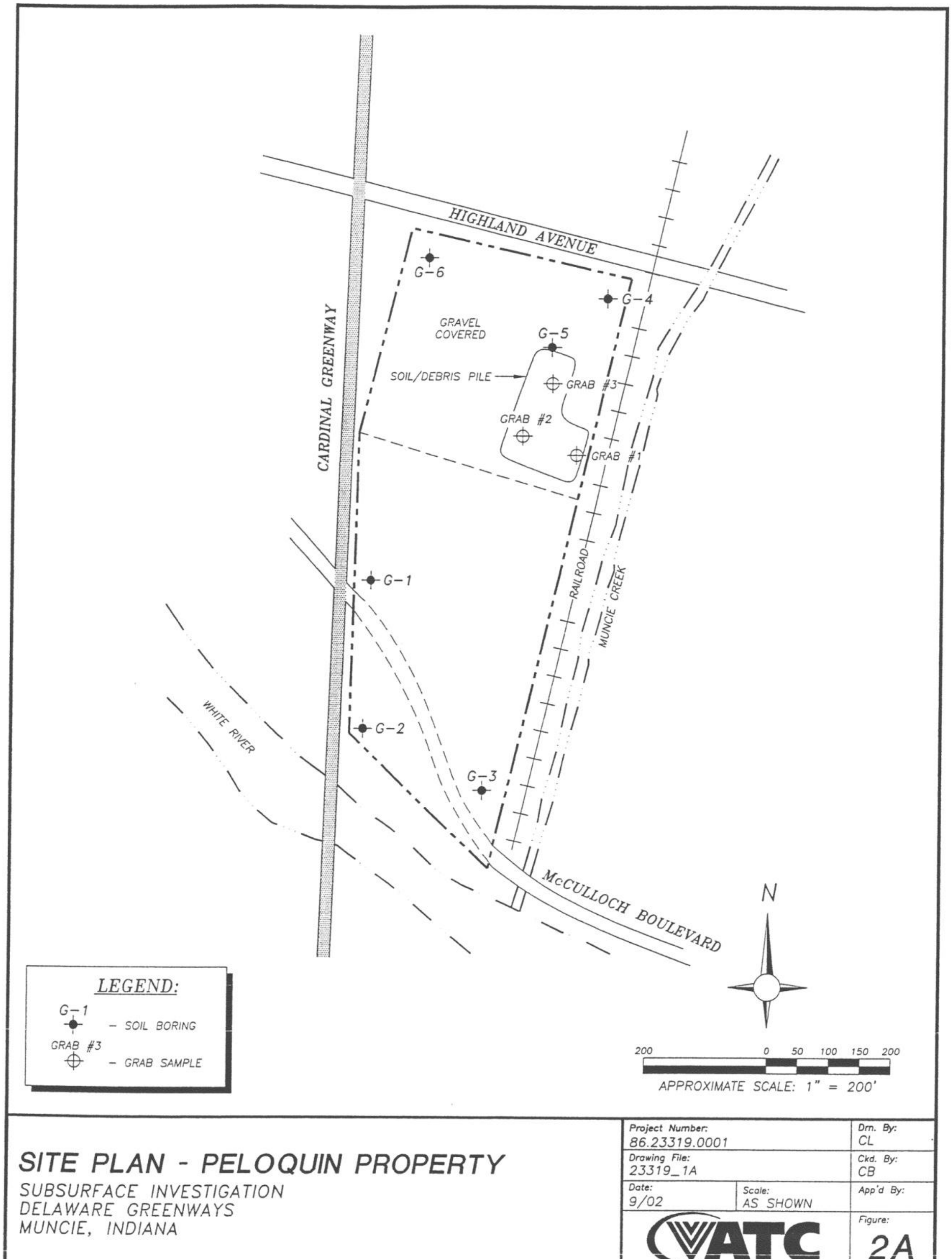
(Chappell, 1997, pg. 5-6)

***Fig. 3.1. Project Site Boundaries***



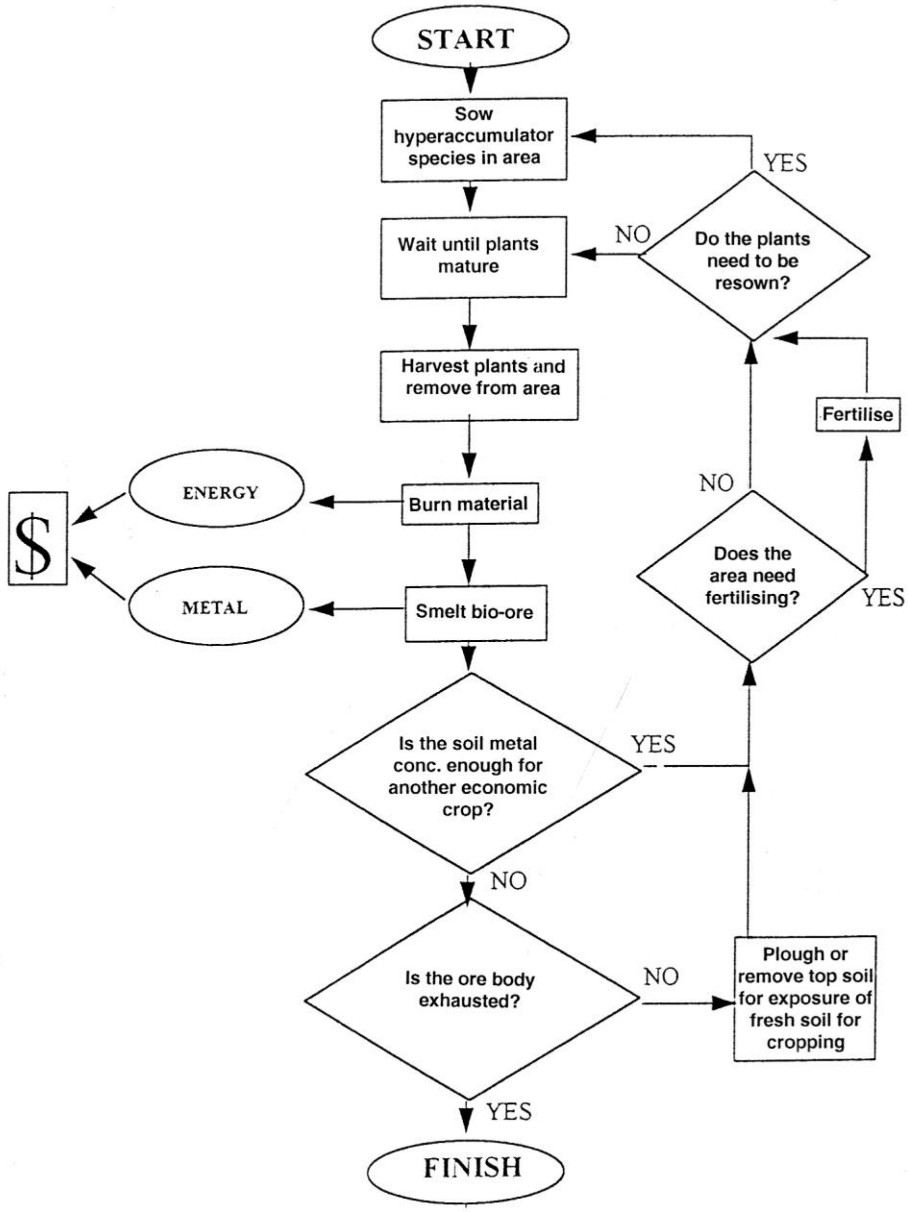

(Symbiont, 2008, pg. 34)

*Fig. 3.2. Symbiont Brownfield Assessment Test Locations*




(Symbiont, 2008, pg. 200)

*Fig. 6.1. Phytomining and Extraction Process Tree Diagram*




(Brooks, 1998, pg. 353)

***Table 6.1. Cost Estimates of a Poplar Tree Phytoremediation System by Ecolotree and Applied and Natural Science, Inc.***

| **Ecolotree** | |
|---|---|
| **Activity** | **Cost** |
| Installation of trees at 1450 trees/acre | \$12,000 to \$15,000 |
| Predesign | \$15,000 |
| Design | \$25,000 |
| Site Visit | \$5,000 |
| Soil cover and amendments | \$5,000 |
| Transportation to site | \$2.14/mile |
| Operation and Maintenance | \$1,500/acre with irrigation<br>\$1,000/acre without irrigation |
| Pruning (not every year) | \$500 |
| Harvest (during harvest years) | \$2,500 |
| **Applied Natural Science** | |
| **Activity** | **Cost** |
| Treemediation program design and implementation | \$50,000 |
| Monitoring equipment | Hardware - \$10,000 |
| | Installation - \$ 10,000 |
| | Replacement - \$5,000 |
| Five-year monitoring | Travel and Meetings - \$50,000 |
| | Data collection- \$50,000 |
| | Annual reports - \$25,000 |
| | Sample collection and analysis - \$50,000 |

* Estimates will vary with type of contaminant, goal of project (i.e., containment vs. removal), and location.

(Chappell, 1997, pg. 5-6)

*Table 6.2. Summary of Physical Remediation Techniques*

| | *Excavation* | *Geotextiles* | *Soil washing* | *Soil vapor extraction* |
|---|---|---|---|---|
| **Access** | yes | yes | yes | yes |
| **Cost ($CAD)** | $5000-$10 000 | <$1000 +excavation costs | $1000-$5000 | $10 000+ |
| **Timeframe** | short <1 season | short <1 season | short <1 season | short <1 season |
| **Effectiveness for UA** | 1 | 2 | 1 | 1 |
| **Environmental Effects** | energy use air pollution disposal | energy use air pollution disposal | energy use air pollution disposal | energy use air pollution disposal |

(Heinegg, 2002, pg. 7)

*Table 6.3 Summary of Bioremediation Techniques*

| | *Microbial remediation* | *Phyto-remediation* | *Fungal remediation* | *Compost remediation* |
|---|---|---|---|---|
| **Access** | yes | yes | no | yes |
| **Cost ($CAD)** | <$1000 | <$1000 | n/a | <$1000 |
| **Timeframe** | short <1 year | 2-5+ years | n/a | short <1 season |
| **Effectiveness for UA** | 2 | 2 | 3 | 2-3 |
| **Environmental Effects** | potential metal toxicity | disposal of toxic plants | potential metal toxicity | none |

(Heinegg, 2002, pg. 9)

***Table 6.4. Estimated Cost Savings Through the Use of Phytoremediation Rather Than Conventional Treatment***

| Contaminant and Matrix | Phytoremediation | | Conventional Treatment | | Projected Savings |
|---|---|---|---|---|---|
| | Application | Estimated Cost | Application | Estimated Cost | |
| Lead in soil (1 acre)[a] | Extraction, harvest, and disposal | \$150,000 -\$250,000 | Excavate and landfill | \$500,000 | 50-65 percent |
| Solvents in groundwater (2.5 acres)[b] | Degradation and hydraulic control | \$200,000 for installation and initial maintenance | Pump and treat | \$700,000 annual operating cost | 50 percent cost saving by third year |
| Total petroleum hydrocarbons in soil (1 acre)[c] | In-situ degradation | \$50,000 - \$100,000 | Excavate and landfill or incinerate | \$500,000 | 80 percent |

(Environmental Protection Agency, 2001, *Brownfields Technology Primer*, pg. 21)

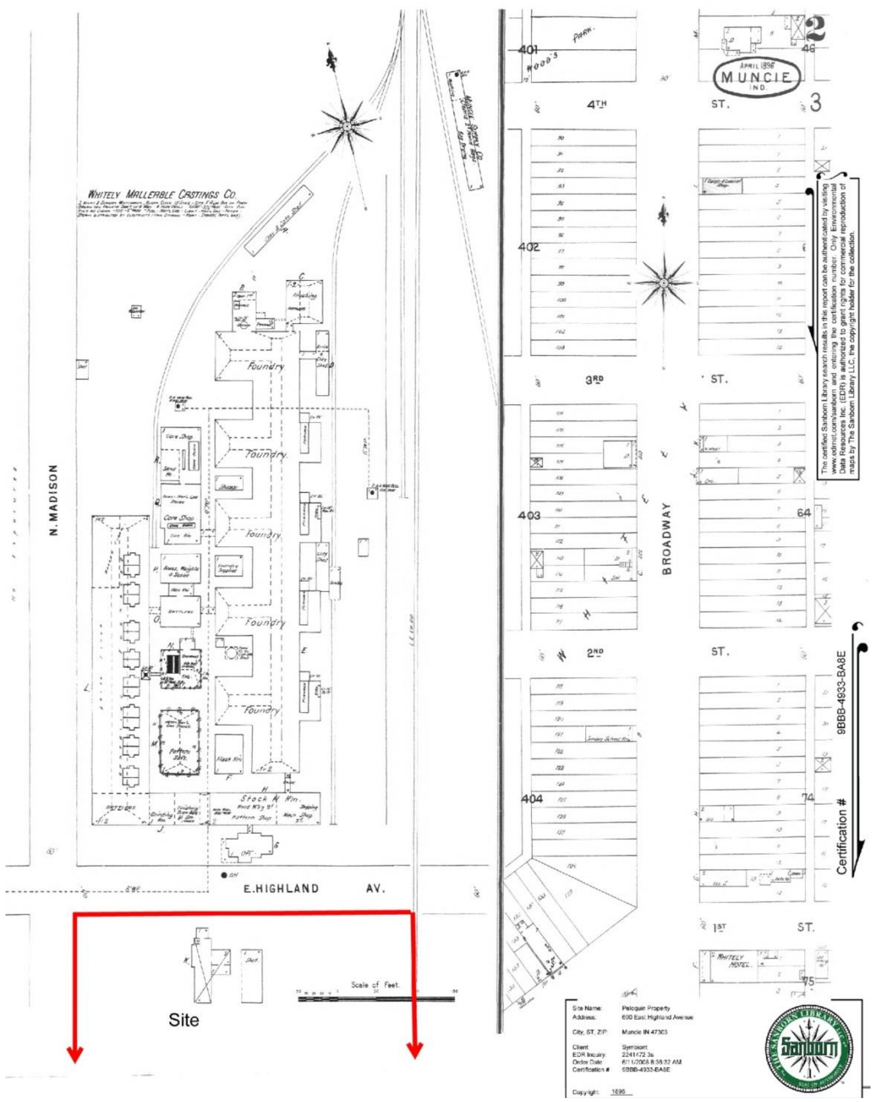
***Table 6.5. Estimates of Phytoremediation Costs Versus Costs of Established Technologies***

| Contaminant | Phytoremediation Costs | Estimated Cost using Other Technologies | Source |
|---|---|---|---|
| Metals | \$80 per cubic yard | \$250 per cubic yard | Black (1995) |
| Site contaminated with petroleum hydrocarbons (site size not disclosed) | \$70,000 | \$850,000 | Jipson (1996) |
| 10 acres lead contaminated land | \$500,000 | \$12 million | Plummer (1997) |
| Radionuclides in surface water | \$2 to \$6 per thousand gallons treated | none listed | Richman (1997) |
| 1 hectare to a 15 cm depth (various contaminants) | \$2,500 to \$15,000 | none listed | Cunningham et al. (1996) |

(Chappell, 1997, pg.5)

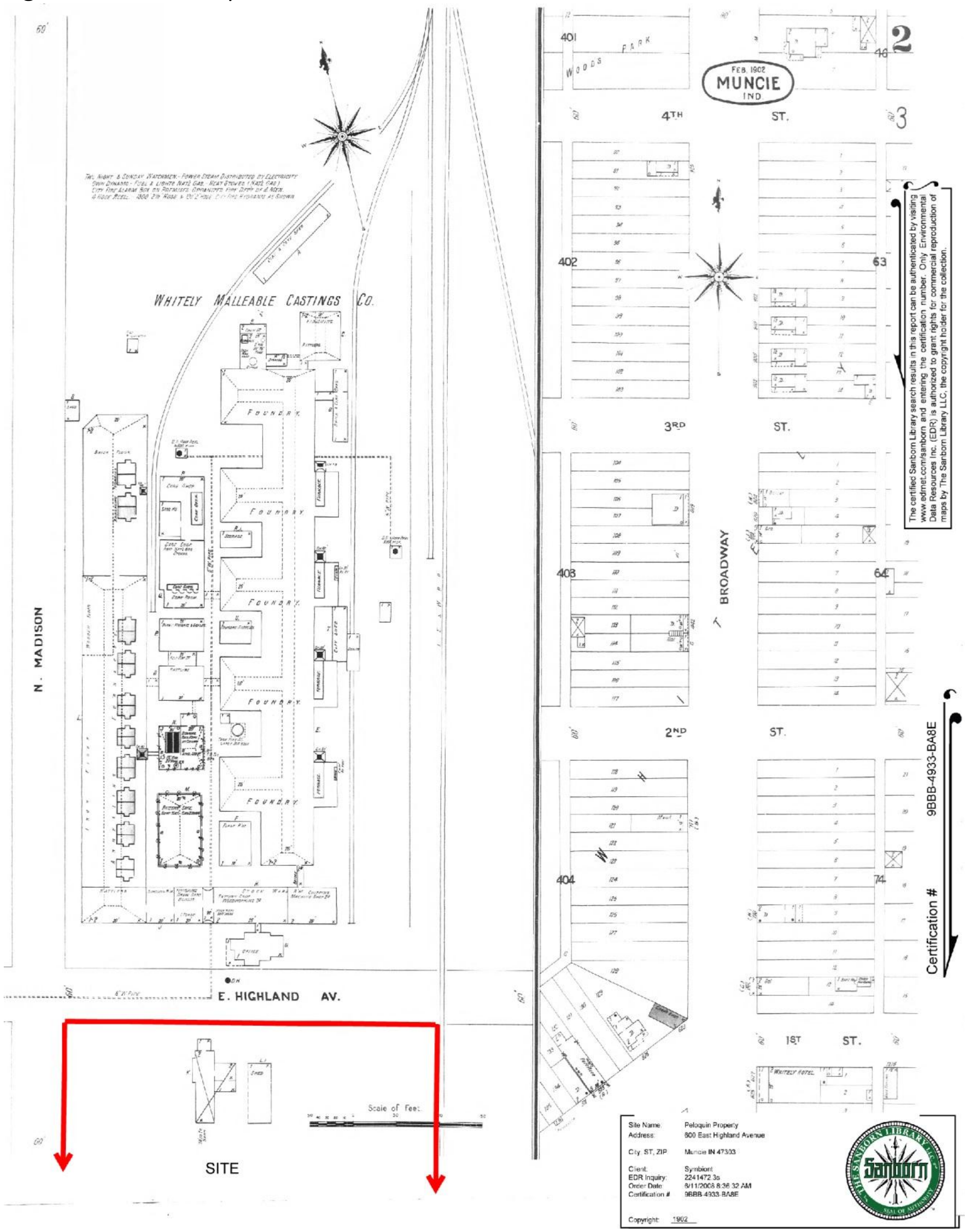
**APPENDIX B**

**Fig. 1.1.** Sanborn map 1896



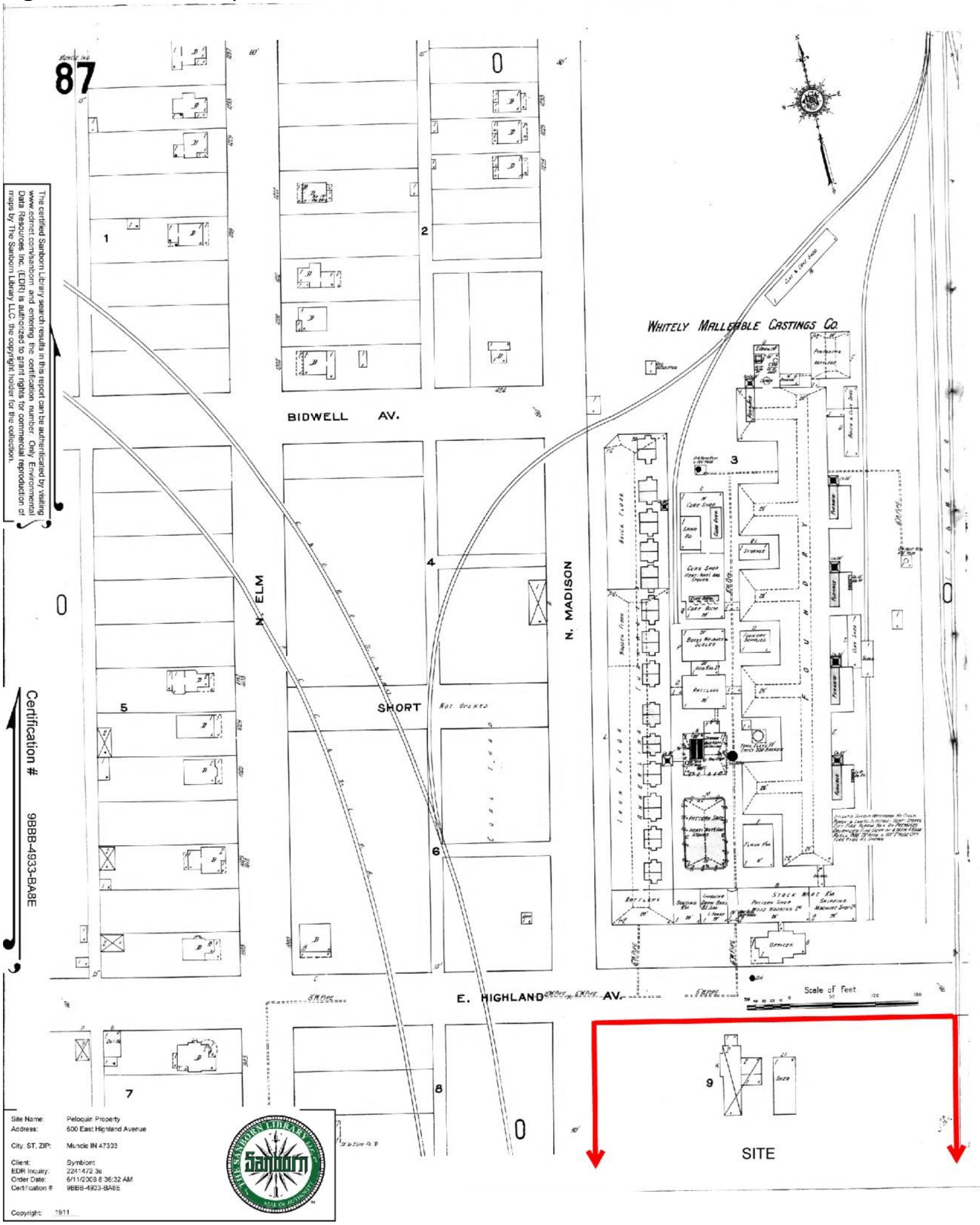

(Symbiont, 2008, pg. 72)

**Fig. 1.2.** Sanborn map 1902



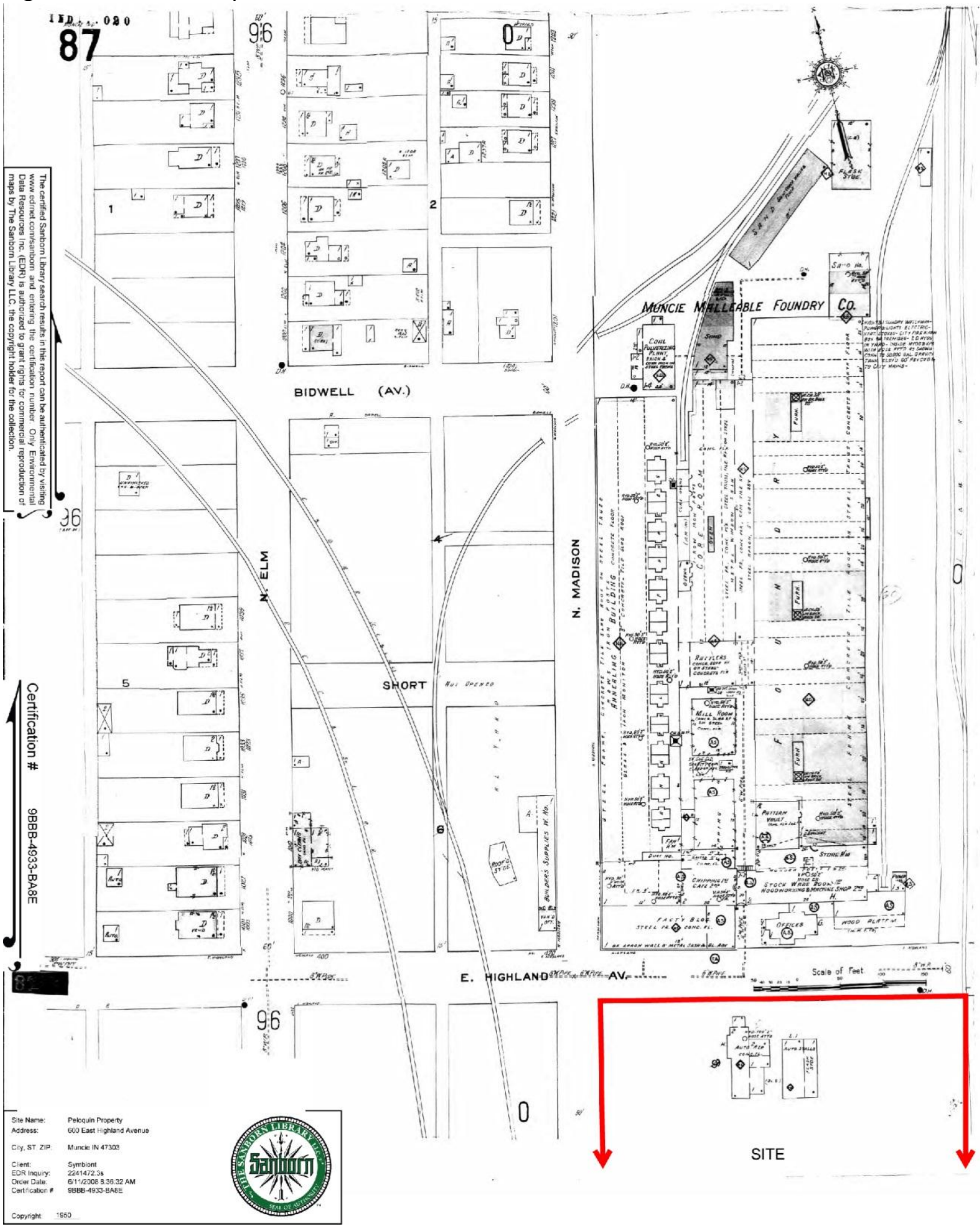

(Symbiont, 2008, pg. 80)

**Fig. 1.3.** Sanborn map 1911



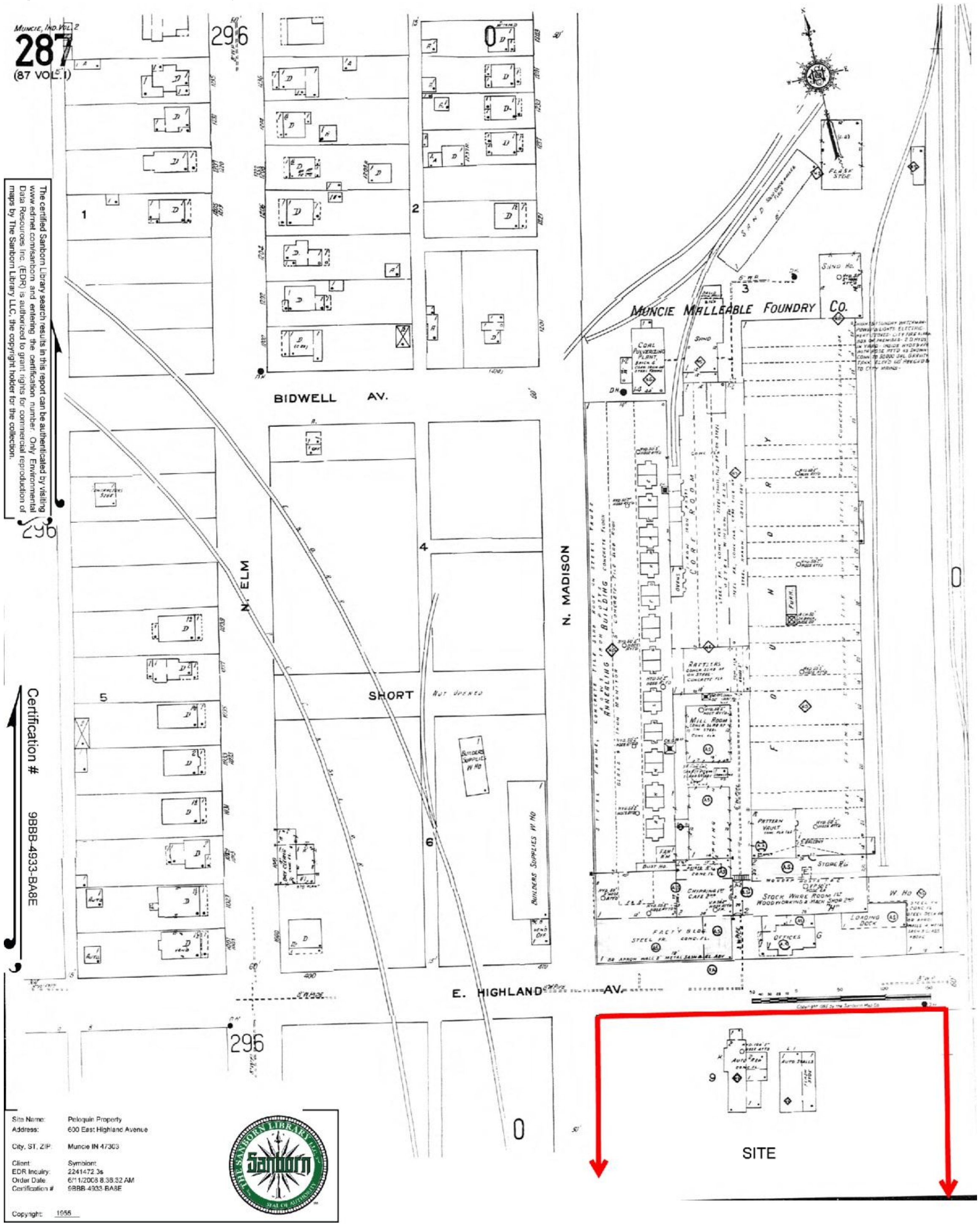

(Symbiont, 2008, pg. 73)

**Fig. 1.4.** Sanborn map 1950



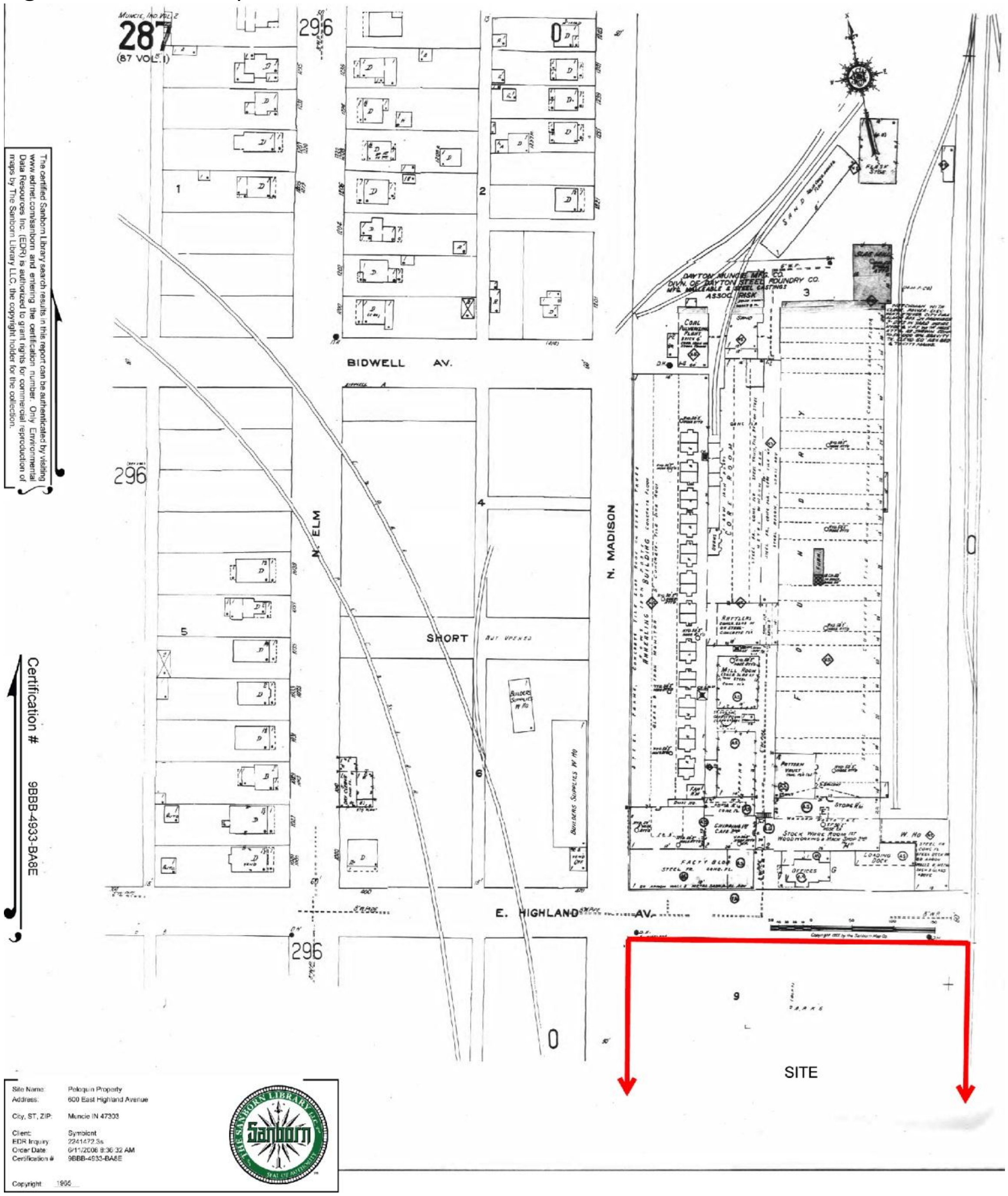

(Symbiont, 2008, pg. 79)

**Fig. 1.5.** Sanborn map 1955



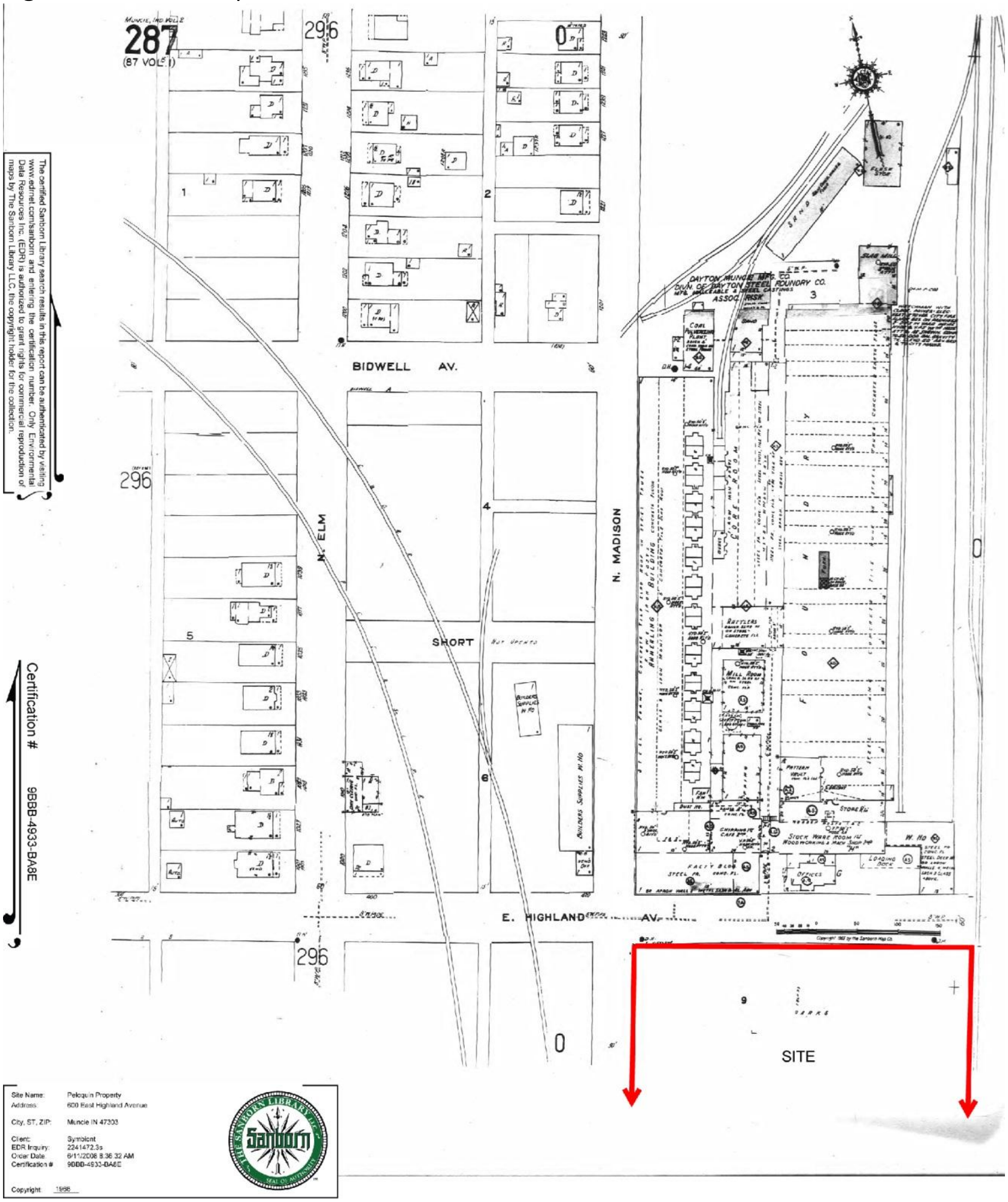

(Symbiont, 2008, pg. 78)

**Fig. 1.6.** Sanborn map 1965




(Symbiont, 2008, pg. 77)

**Fig. 1.7.** Sanborn map 1966




(Symbiont, 2008, pg. 76)